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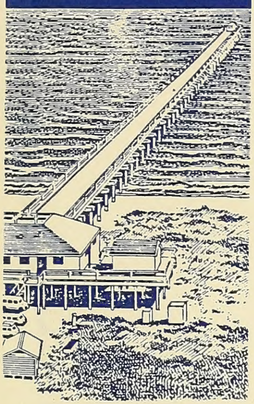

TECHNICAL REPORT CERC-84-6

HURRICANE ALICIA STORM SURGE AND WAVE DATA

by

Andrew W. Garcia, Thomas H. Flor

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631
Vicksburg, Mississippi 39180-0631

US ARMY ENGINEER WATERWAYS EXPERIMENT STATION

November 1984

Final Report

Approved For Public Release; Distribution Unlimited

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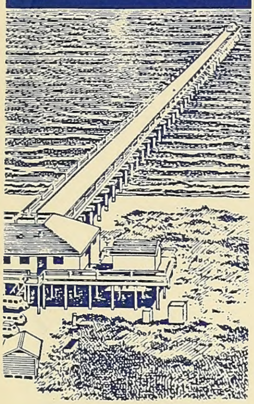

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A summary of storm surge highwater mark hydrograph and wave data acquired during and subsequent to Hurricane Alicia is presented. The data were obtained and assembled as part of a long-term research effort by the Corps of Engineers to establish a quantitative data set with the objective of providing, in a series of documents, the data necessary for simulation and verification of numerical surge models. The data contained herein were obtained primarily by the Waterways Experiment Station and the Galveston District (Continued)

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20. ABSTRACT (Continued).

of the Corps of Engineers with supplemental data from contributing agencies and institutions. Additional information is included in the form of photographs and descriptive narrative to aid investigators in assessing the degree of importance of an individual measurement for the purpose of model verification.

PREFACE

The information and data presented herein were assembled and analyzed in 1983-1984 as a mission requirement of the Hurricane Surge Prototype Data Collection work unit, Coastal Flooding and Storm Protection Program, Coastal Engineering Area of Civil Works R&D under No. 321-31662. Mr. John H. Lockhart, Jr., and Mr. John Housley are the Office, Chief of Engineers, technical monitors for the Coastal Engineering Research Area. The work unit is a multiyear project of the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), under the general supervision of Dr. Robert W. Whalin, Chief of CERC, Dr. Lewis E. Link, Assistant Chief of CERC, Dr. Fred E. Camfield, Acting Chief of the Engineering Development Division, and Dr. Dennis R. Smith, Chief of the Prototype Measurement and Analysis Branch. Mr. Andrew W. Garcia is the Principal Investigator of the Hurricane Surge Prototype Data Collection work unit. Mr. Thomas H. Flor is the engineer in charge of data collection activities. This report was prepared by Messrs. Garcia and Flor.

Commanders and Directors of WES during the conduct of this study and the preparation and publication of this report were COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
knots	0.5144444	metres per second
miles (US statute)	1.609344	kilometres
miles per hour (US statute)	1.609344	kilometres per hour
millibar	100.0000	pascal
square miles (US statute)	2589.9980	square kilometres

HURRICANE ALICIA STORM SURGE AND WAVE DATA

PART I: INTRODUCTION

Background

1. The Hurricane Surge Prototype Data Collection Work Unit was initiated in 1980, the year the last hurricane (Allen) made landfall in the continental United States prior to hurricane Alicia in August 1983. Alicia provided the first opportunity to employ techniques and methodologies developed under the work unit during actual hurricane conditions.

2. Alicia had atypical origins since it developed in the central Gulf of Mexico and made landfall less than 2 days after showing signs of deepening into a significant storm. Alicia's rapid development required an especially quick response by the hurricane surge data collection field team. The field team was in the vicinity of predicted landfall within 12 hr of the time Alicia was upgraded to a hurricane. The forecast position issued by the National Hurricane Center at that time indicated Alicia would make landfall before daylight on 18 August; consequently, the field team worked assuming they had only 1 day of daylight to deploy onshore gages.

3. This report is the second in a series* providing a data base directed toward verification of numerical storm surge models. As such, the emphasis is on quantitative measurements of the hydrodynamic and meteorological parameters of Alicia rather than documentation of structural damage or changes in coastal morphology. The photographs referred to in Part V are intended to assist investigators in assessing the applicability of individual highwater marks in verifying a given numerical model.

Purpose and Scope

4. This report contains coastal and inland hydrographs, highwater marks, significant wave height and wave spectra, and basic meteorological data associated with hurricane Alicia. The data contained herein have been compiled from a variety of sources; consequently they cannot be guaranteed to be 100 percent accurate. Nevertheless, every reasonable effort was made and great care was taken to ensure that the data are the best and most complete available.

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* Thomas H. Flor. 1983 (Jul). "Poststorm Reconnaissance of Tropical Storm Chris," Miscellaneous Paper HL-83-5, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

PART II: METEOROLOGICAL DISCUSSION

5. Hurricane Alicia was the first storm of the 1983 hurricane season. Alicia was classed as minimal category 3 at landfall on the Saffer-Simpson scale which ranges from 1 to 5. Alicia was an unusual system because it formed in a region of high pressure, about 1015 mb,* which probably contributed to the storm's development out of an otherwise not very intense low pressure system. At about midday on 16 August the system began to deepen and continued to do so for the 40 hr remaining before landfall.

6. Alicia was officially classed as a hurricane at 0000 Greenwich mean time (GMT) 17 August 1983. Central pressure was 991 mb with maximum sustained winds of 75 mph. The hurricane continued to intensify until it made landfall at the western tip of Galveston Island, Texas, at approximately 0700 GMT 18 August. Central pressure was 963 mb with maximum sustained winds of about 115 mph. Table 1 is the best track information available as of February 1984. Radar imagery indicates Alicia may have developed a double-eye structure subsequent to landfall. The two eyes probably did not always exist simultaneously, thereby causing the hurricane track to appear very erratic if eye position is used to determine the track. Use of a mass field envelope technique will probably result in a much smoother track. After moving north of Houston, Alicia weakened steadily and was classed as a tropical depression at 0600 GMT 19 August. Figure 1 shows the approximate track of Alicia.

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* A table of factors for converting inch-pound units of measurement to metric (SI) units is presented on page 3.

Table 1

Preliminary Best Track, Hurricane Alicia

(As Published by National Hurricane Center)

1983 Date	Time GMT	Position, deg Latitude	Longitude	Pressure mb	Wind knots	Stage
8/15	1200	27.3	90.5	1009	30	Tropical depression
8/15	1800	27.2	91.0	1006	40	Tropical storm
8/16	0000	27.1	91.5	1005	45	Tropical storm
8/16	0600	27.0	92.0	1004	50	Tropical storm
8/16	1200	27.1	92.4	1002	55	Tropical storm
8/16	1800	27.3	92.8	998	60	Tropical storm
8/17	0000	27.4	93.3	991	65	Hurricane
8/17	0600	27.7	93.7	987	70	Hurricane
8/17	1200	27.9	94.2	983	75	Hurricane
8/17	1800	28.1	94.5	974	90	Hurricane
8/18	0000	28.4	94.8	969	95	Hurricane
8/18	0600	28.9	95.0	963	100	Hurricane
8/18	1200	29.7	95.5	965	80	Hurricane
8/18	1800	30.5	96.0	990	40	Tropical storm
8/19	0000	31.5	96.7	998	35	Tropical storm
8/19	0600	32.4	97.4	1003	30	Tropical depression
8/19	1200	33.3	98.0	1006	25	Tropical depression
8/19	1800	34.4	98.5	1009	25	Tropical depression
8/20	0000	35.4	99.0	1010	20	Tropical depression
8/20	0600	36.5	99.4	1011	20	Extratropical
8/20	1200	37.6	99.2	1011	20	Extratropical
8/20	1800	38.9	99.0	1011	20	Extratropical
8/21	0000	40.0	98.0	1010	20	Extratropical
8/21	0600	41.2	97.0	1010	20	Extratropical

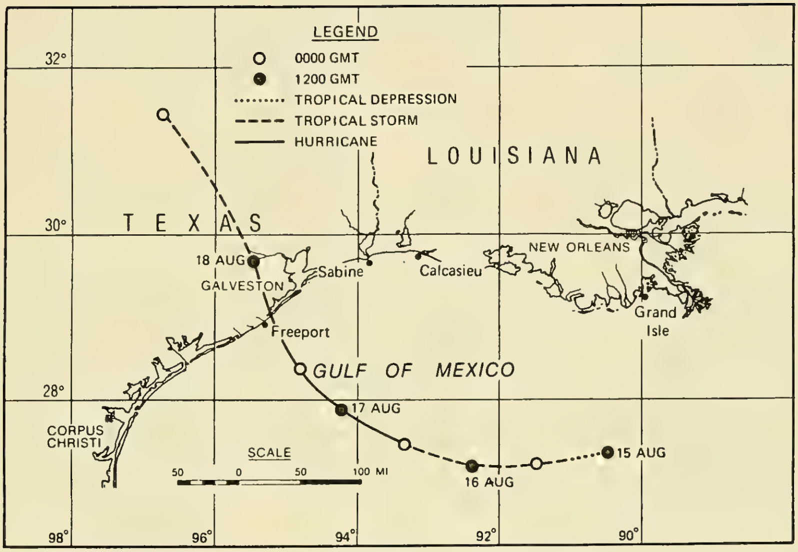


Figure 1. Approximate track of hurricane Alicia

PART III: SURGE MEASUREMENTS

7. Alicia's development had been closely monitored by the staff of the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), and when rapid deepening became evident about noon on 16 August it was decided to deploy the CERC hurricane surge data collection field team. The team departed from WES late afternoon on 16 August and was in the Houston-Galveston vicinity at daybreak on 17 August. Galveston Island, by this time, was being evacuated. Coastal water levels had already risen and, with the high sea state, prevented deployment of onshore gages along the ocean side of Galveston Island and lower Galveston Bay. Guidance from the National Hurricane Center indicated the storm would probably make landfall between Corpus Christi and Freeport, Texas, on Matagorda Bay. Therefore, the field team departed the Houston-Galveston area for the Matagorda Bay area. Enroute, the team deployed a one-gage package at Baytown, Texas, near the head of Galveston Bay in the event that Alicia turned northward, as it later did.

8. During the time remaining before the predicted landfall, the field team worked in the Matagorda Bay area deploying gage packages at Port Lavaca and Palacios, Texas. At about 2200, 17 August, approximately 4 hr before landfall, the field team retreated to Houston to wait out the storm.

9. On 19 August following passage of the storm, the field team returned to the Galveston area to begin the poststorm survey. Details of the survey are given in Part V.

PART IV: HYDROGRAPHIC DATA

Locations of Tide Gages

10. The locations of tide gages within Galveston Bay that recorded useable data are shown in Figure 2. In addition to records from these gages,

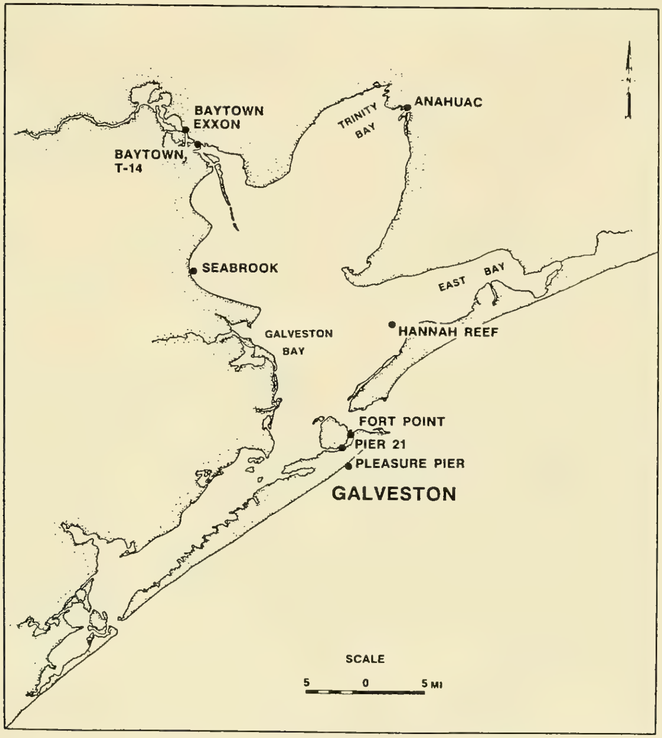


Figure 2. Locations of tide gages in Galveston Bay area

records from Freeport and Lake Sabine, Texas, and Calcasieu Pass, Louisiana, were used. Table 2 lists the location, responsible agency or institution, maximum water elevation, time and date, and reference datum for each of the hydrographs obtained. For several of the hydrographs, the time of maximum water was estimated from a series of diagnostic numerical model runs performed at the National Hurricane Center using the SLOSH model (Sea-Lake Overland Surges from Hurricanes). This procedure was necessary because the times on

Table 2

Hydrograph Information

Location	Agency	Max Elevation, ft	Time	Datum
Freeport, Tex.	NOS	4.0	0630/17/08/83	NGVD
Pleasure Pier, Galveston, Tex.	NOS	9.0	0130/18/08/83	NGVD
Pier 21, Galveston, Tex.	NOS	5.8	0200/18/08/83	NGVD
Fort Point, Galveston, Tex.	CE	6.1	0200/18/08/83	NGVD
Seabrook, Tex.*	CE	8.5	0430/18/08/83	NGVD
T-14, Baytown, Tex.**	CE	6.1	0245/18/08/83	NGVD
Baytown Refinery, Tex.	EXXON Corporation	10.2	0730/18/08/83	MSL
Anahuac, Tex.**	Texas State Water Resources Board	8.0	0800/18/08/83	NGVD
Hannah Reef, Tex.*	CE	6.0	0400/18/08/83	NGVD
Sabine Lake, Tex.*	CE	4.1	1400/17/08/83	NGVD
Calcasieu Pass, La.	CE	4.0	1600/17/08/83	NGVD

Note: NOS = National Ocean Service.
CE = Corps of Engineers.
NGVD = National Geodetic Vertical Datum.
MSL = mean sea level.
* Time of peak surge estimated.
** Incomplete hydrograph, see text.

the hydrographs were obviously in error; in most instances the recorded times showed the peak surge within the bay occurring before the peak surge outside the bay.

11. The National Hurricane Center's SLOSH model was used because the basin grid containing Galveston Bay had already been developed by the Center, and the meteorological data from Alicia necessary to execute the runs were in residence and available. The model runs were verified by comparing the computed surge with the recorded surge at Pleasure Pier, Pier 21, and the EXXON Baytown Refinery gages.

12. Plates 1-10 are hydrographs at the specified locations. The Pleasure Pier and Pier 21 hydrographs show the peak of the surge coincides with the predicted high tide. Assuming the tide and surge effects are linearly superimposed, the surge relative to the predicted tide is about 7.4 ft at the Pleasure Pier on the ocean side and 4.9 ft at Pier 21 on the bay side of Galveston Island. At Freeport, Texas, there were three peaks, two on 17 August 1 day prior to landfall and one approximately coinciding with landfall. The three peaks are about 2.9, 3.1, and 2.5 ft relative to the predicted tide. The highest surge value did not occur at landfall because of Freeport being on the "backside" of the storm; i.e., the winds at Freeport were primarily offshore at the time.

13. As shown in Figure 2, the Pier 21 and Fort Point gages are located quite close to one another and the hydrographs reflect this. The Hannah Reef gage, located on the side of the bay opposite Pier 21 and Fort Point gages, shows a lower peak followed by a relatively long tail. The broader peak was probably caused by waters being moved out of Fort Bay into the northwest reaches of Galveston Bay by the predominantly southeast winds during the storm and then flowing back after the storm had passed.

14. The Anahuac gage recorded until it was submerged; attempts were made to determine a high-water elevation nearby but the adjacent land was flat and featureless and overgrown with scrub vegetation.

15. The hydrograph obtained at the EXXON Corporation's Baytown Refinery is a combination of readings from a strip-chart recorder and digital readout. The strip-chart recorder had a maximum excursion corresponding to about an 8-ft elevation. The water level sensor continued to function normally, driving a remote readout from which surge heights were logged manually. The maximum surge recorded at the Baytown Refinery agrees very closely with nearby high water marks.

16. The CERC field team deployed two surge packages in Matagorda Bay, one at Port Lavaca and the other one at Palacios, Texas. Data from these gages

showed no significant departure from the expected tide during passage of the storm. This was not unexpected as these gages were on the backside of the storm about 70 miles from the point of closest approach.

17. The CERC gage T-14 functioned until about 0300 CDT 18 August when it failed. The cause of the failure was determined to be a defective pressure case which allowed water into the electronic circuits. Reduction and correction of the available data from T-14 is discussed in the following section.

Correction of Absolute Pressure Tide Recorders

18. Use of an uncompensated pressure-measuring sensor such as that employed in this program requires the data to be compensated for changes in atmospheric pressure during passage of the storm. A change of 1 in. of mercury in atmospheric pressure is approximately equivalent to a change of 1 ft in water level. Changes in atmospheric pressure of 2 in. of mercury are common during passage of a storm; consequently, it is essential that such changes be taken into account when computing a hydrograph from uncompensated pressure data.

19. The simplest and most accurate means of compensating the pressure record would be to place a barograph near the tide gage; however, this is seldom feasible from both logistic and economic standpoints. An alternative method is by means of an analytic model to interpolate in time and space using data observed elsewhere in the affected area. There are a number of models to choose from, some developed from theoretical considerations, others by empirical best fit to the smoothed pressure profiles of several hurricanes.

20. The model found to give the best fit to the observed data for Alicia is

$$\frac{P - P_o}{P_\infty - P_o} = C \left(\text{arc tangent } \frac{r}{r_o} \right)$$

where

P = pressure to be computed

P_o = central pressure of storm

P_∞ = far field pressure

C = constant (set to 0.6 for Alicia)

r = distance from storm center at which pressure is to be computed

r_o = radius to maximum winds

21. Plate 11 shows the comparison of observed and computed pressures at Galveston, Texas. Plate 12 shows the comparison of observed and computed pressures at Alvin, Texas. These stations were the two closest to Alicia's track immediately after landfall. Plate 13 shows the computed barogram at the site of T-14 near Baytown, Texas. Plate 14 shows both the compensated and uncompensated hydrographs from the T-14 location.

Wave and Tide Data

22. During Alicia's passage through the Gulf of Mexico, CERC was operating wave and tide gages on three Shell Oil Company petroleum platforms off the south Louisiana coast. The locations of the platforms are shown in Figure 3. The positions and nominal water depths of the platforms are:

	Latitude		Longitude		
Platform Designation	deg	min	deg	min	Water Depth, ft
Bay Marchand 2Q	28	58.8	90	10.5	55
Eugene Island	29	03.7	91	26.7	25
Vermillion 22	29	28.2	92	33.0	32

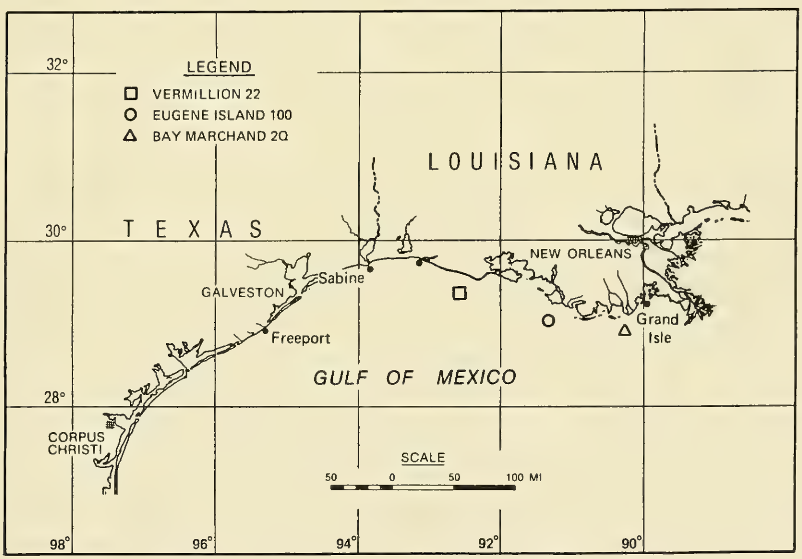


Figure 3. Location of Shell Oil Company platforms off Louisiana coast

23. Plates 15-17 are the significant wave heights at each of the platforms during the storm passage. The wave data were acquired by using a subsurface pressure sensor and a self-contained, internally recording digital data logger. The pressure records were cosine tapered and spectrally analyzed by means of a Fast Fourier Transform algorithm. Each spectral component was then corrected for depth attenuation by using linear-wave theory and the periodogram block averaged resulting in a spectrum with 32 equivalent degrees of freedom. Spectral plots of the wave data acquired during Alicia's passage are contained in Appendix A.

24. Plates 18-20 are hydrographs obtained at the Shell platforms for the month of August 1983. The dates of Alicia's passage through the Gulf of Mexico were approximately 15-20 August 1983. The hydrograph obtained at Vermillion 22 shows a departure of about 1.25 ft from the expected tide range on 17 and 18 August. Hydrographs obtained at Eugene Island and Bay Marchand show almost no departures from the expected tide.

PART V: POSTSTORM SURVEY OF HIGH WATER LEVELS

25. A poststorm visual survey of high water marks was made during the period 21-23 August 1983 from Matagorda Bay east to High Island, Texas, including the shoreline of Galveston Bay. The westernmost extent of surge-induced flooding appeared to have been in the vicinity of Sargent, Texas, at the eastern end of Matagorda Bay. Coastal flooding in this area, due to storm surge and wave setup, overtopped the low berm on the beach and built numerous washover fans on vegetated wetlands between the beach and a high man-made dune along the Intracoastal Waterway. The surge-generated component of this rise in water level appeared not to exceed +3 ft NGVD. Debris lines along the banks of the Intracoastal Waterway indicated a rise in water level of approximately +2 ft NGVD.

26. At the US Coast Guard Station in Freeport near the mouth of the Old Brazos River, high water overtopped a low bulkhead approximately 3 ft above the normal water line but caused minimal flooding of the station itself (Photo 1). Nearby in Surfside Beach, the surge and wave setup breached the primary dune and damaged the coastal highway which is at an elevation of +8 ft NGVD. Between Surfside Beach and San Luis Pass, the approximate point of landfall, the surge overtopped the roadbed at an elevation of +8 ft NGVD and caused extensive damage to the highway (Photos 2-4). The entire eastern tip of Follets Island at San Luis Pass appeared to have been inundated by the surge.

27. Between San Luis Pass and Jamaica Beach, 10 miles to the east, the surge exceeded +9 ft NGVD, overtopping Highway 257, the highest point on the western end of Galveston Island. Residences in the area exhibited extensive damage primarily from wind action. The total rise in water level reached approximately +11 ft NGVD in Jamaica Beach and tapered to about +7 ft NGVD near the western end of the Galveston seawall. Water levels rose from both the Gulf of Mexico and West Bay sides on this portion of the island but did not exceed the elevation of the coastal highway.

28. In the city of Galveston the storm surge did not exceed the +15 ft NGVD elevation of the seawall. Storm damage was limited to wind damage, some wave overtopping of the seawall, and flooding of low-lying areas near the causeway on the bay side. At East Beach, seaward of the Galveston seawall, the surge reached approximately +7 ft NGVD, causing extensive damage to

residences and commercial buildings and leaving large debris piles at the base of the seawall (Photos 5-7). Surge levels on the Bolivar Peninsula reached +7 to +8 ft NGVD between the western end of the peninsula and Crystal Beach, rising from both the Gulf and Bay sides of the peninsula but failing to inundate Highway 87 and many homes built on high ground along the highway. Photo 8 shows several homes on the beach damaged or destroyed by the storm; however, most homes further inland showed signs of wind damage but no flooding damage. At High Island, 50 miles east of the point of landfall, the surge reached +4 to +5 ft NGVD, flooding extensive low-lying marsh areas and depositing large amounts of sand on Highway 87 (Photos 9 and 10).

29. At Virginia Point, just north of Galveston Island, the surge covered the Gulf Freeway up to approximately +7 ft NGVD, cutting off all access to the island during the height of the storm. The Texas City dike was overtopped along most of its length, but the Texas City levee system protected the city from surge-induced flooding. The surge along this section of the bay is estimated to have been between +7 and +10 ft NGVD. At Seabrook, 15 miles north of Texas City, the storm surge reached approximately +9 ft NGVD. The water level remained considerably higher than normal in this area for at least 3 days after landfall (Photo 11).

30. High water marks on the Highway 146 bridge at Baytown indicated a surge at the north end of Galveston Bay of approximately +10 ft NGVD. Photo 12 shows the eastern end of the bridge causeway. The water level in this area rose 3 to 4 ft above normal by the morning of 17 August and remained several feet higher than normal for at least 3 days after landfall. East of Baytown, in the Houston Point area, the shoreline is backed by bluffs 15 to 20 ft high which prevented significant surge damage. No definite high water marks were located in this area.

31. The maximum water level at Anahuac, in the northeast corner of the bay, exceeded +8 ft NGVD, flooding a Texas Water Resources Board recording tide gage. The topography in this area is flat and low-lying, allowing the surge to propagate north past the Interstate 10 crossing of the Trinity River 7 miles north of Anahuac. Debris along the I-10 causeway indicated a surge level near +10 ft NGVD. At Smith Point, 15 miles south of Anahuac, high water marks in a county park indicated a rise in water level of approximately +5 ft NGVD. Smith Point and the bay shoreline to the east are low-lying wetland areas that were inundated by the surge except for high ground along

Highway 562 and isolated high spots 5 to 10 ft above NGVD.

32. A series of contour maps showing high water marks in the Houston, Anahuac, Winnie, Galveston, Alvin, and Freeport, Texas, area are presented in Appendix B.

33. Appendix C shows the flight lines and photograph numbers for color aerial photography of the Texas Gulf Coast taken on 24 August 1983.

PART VI: CONCLUDING REMARKS

34. Alicia was a minimal category 3 (Safir-Simpson scale) hurricane with maximum winds of only 115 mph, yet it was the second costliest hurricane ever to strike the United States. Considering that Alicia was not particularly severe and most of the damage occurred in Houston, well away from the coast, the disaster potential of a large, intense hurricane making landfall in a heavily populated coastal region is clearly evident. That Alicia was not a more costly storm can be at least partially attributed to the existence of the seawall at Galveston built in the aftermath of the disastrous 1900 hurricane. Other coastal areas affected by the storm were spared extensive damage because they were sparsely populated and/or consisted of a high proportion of dwellings constructed to withstand the effects of storms and surges.

35. The correlation of the survival of coastal structures with measured surge levels provides a valuable data base for establishment or refinement of standards and guidelines for construction in high-risk coastal zones. As a consequence, the acquisition of reliable, quantitative data, particularly hydrographs, is invaluable in delineating storm conditions under which coastal structures survive or fail. Moreover, because numerical surge models are themselves time-stepping procedures, improvements of the models are highly dependent upon time series data.

36. As mentioned earlier in this report, Alicia was a particularly severe test of the ability of the field team to quickly mobilize and reach the predicted vicinity of landfall; the procedures developed as part of this research effort proved to be well suited to the requirements of rapid deployment. The surge gage, deployed in Baytown, Texas (Site T-14) early in the deployment phase when Alicia was predicted to make landfall in the Corpus Christi/Port Lavaca area, demonstrated the soundness of the site-selection procedure; whereby a small number of widely separated sites were initially occupied, with the more likely reaches of shoreline being filled as the storm neared the coast.

37. A particular shortcoming uncovered during the post-Alicia survey was the length of time before retrieval of some of the hydrographs. The necessity for estimating the time of peak surge by means of a numerical model for these hydrographs was caused by substantial clock errors that existed prior to the arrival of the storm and were compounded by the lengthy interval

between passage of the storm and an observer arriving on the site to annotate the tide-gage record. Such difficulties could be minimized during future storms if someone from the local field operating office or a member of the surge field team were designated to recover the hydrographs as quickly as feasible subsequent to a storm's passage.

38. The tide records and wave data acquired on the Shell Oil Company platforms constitute particularly unusual data sets in that gradients of the surge amplitude and growth/decay of the wind-generated waves as functions of fetch and time can be estimated. The close agreement at all three locations (Bay Marchand, Eugene Island, Vermillion) of the dominant wave period (about 8.5 sec during the height of the storm) leaves no doubt as to the origin of the waves.

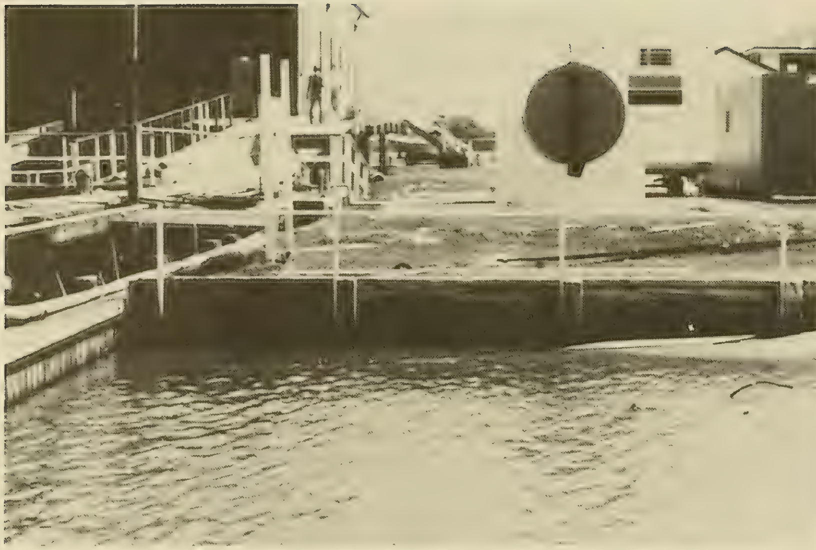


Photo 1. Debris line above bulkhead at US Coast Guard Station, Freeport, Texas

Photo 2. Highway damage on Follets Island 2 miles west of San Luis Pass

Photo 3. Highway damage on Follets Island near San Luis Pass

Photo 4. Highway damage near eastern end of Follets Island

Photo 5. Damaged mobile homes and debris on East Beach, Galveston

Photo 6. Debris line at foot of seawall, East Beach, Galveston

Photo 7. Damage to commercial property on East Beach, Galveston Island

Photo 8. Damage to beachfront homes at Crystal Beach, Bolivar Peninsula

Photo 9. Overwash deposits on Highway 87 at High Island

Photo 10. Overwash deposits at intersection of
Highways 87 and 129 on High Island

Photo 11. Residual flooding at Seabrook, Texas, 21 August 1983

Photo 12. Debris line and stranded tug on Highway 146 embankment, Baytown, Texas

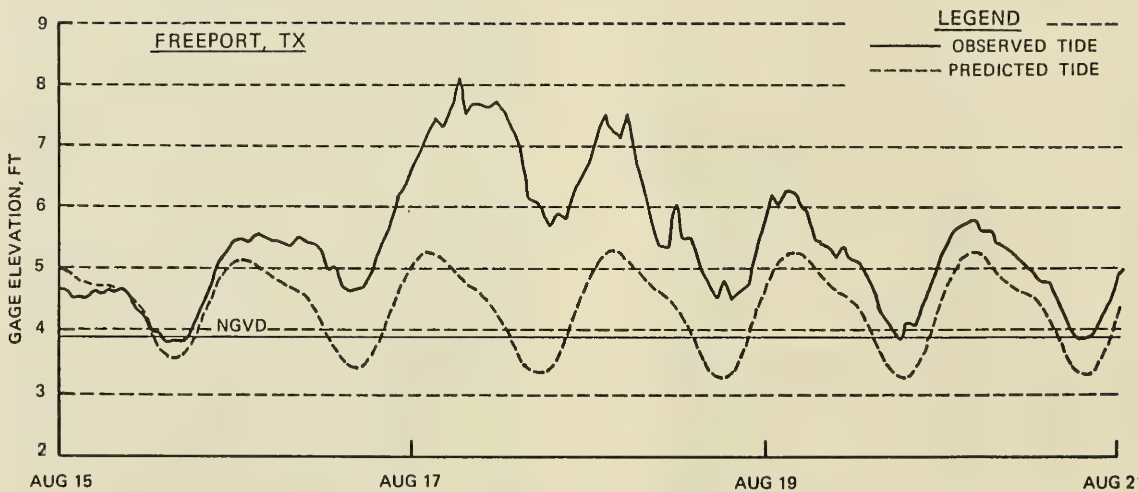


Plate 1. Hydrograph, Freeport, Texas

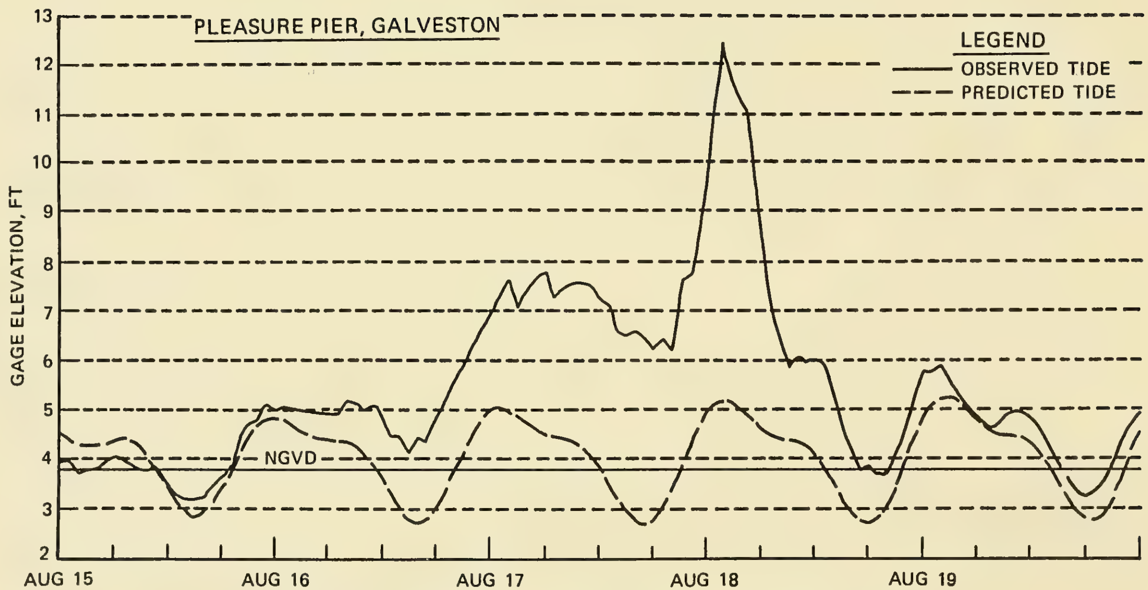


Plate 2. Hydrograph, Pleasure Pier, Galveston, Texas

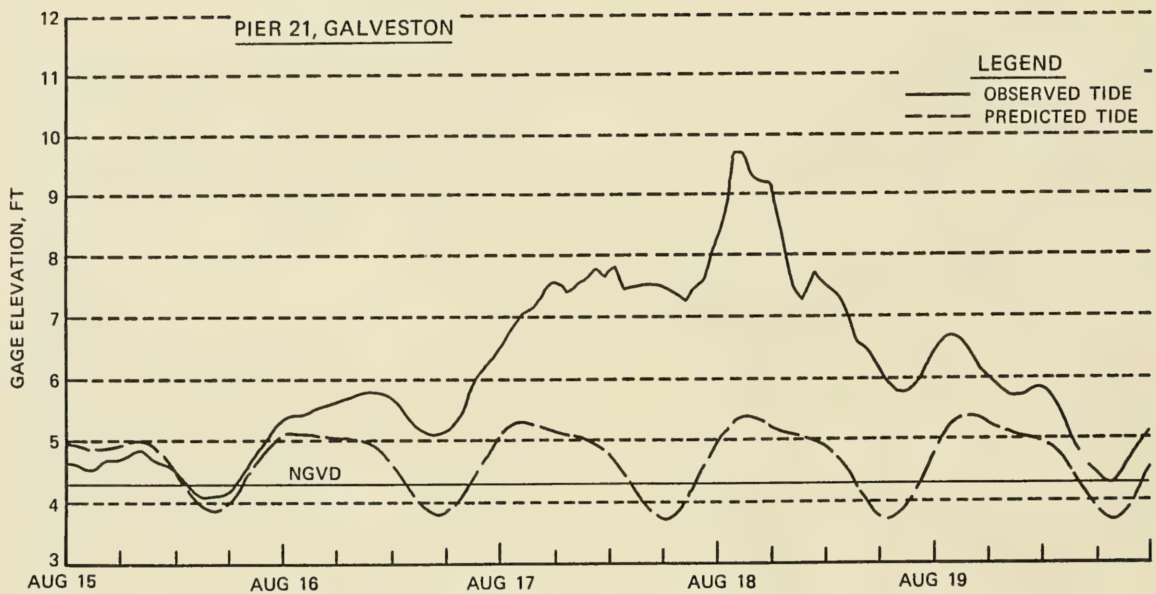


Plate 3. Hydrograph, Pier 21, Galveston, Texas

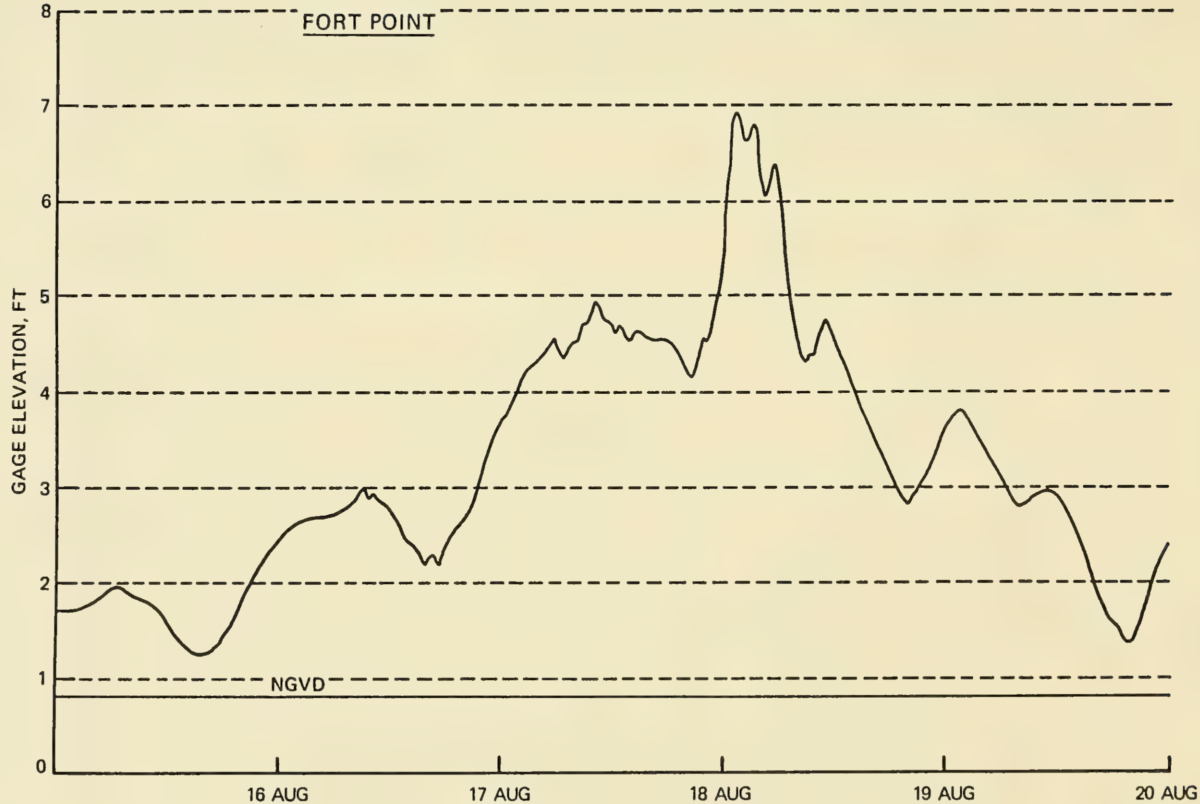


Plate 4. Hydrograph, Fort Point, Galveston, Texas

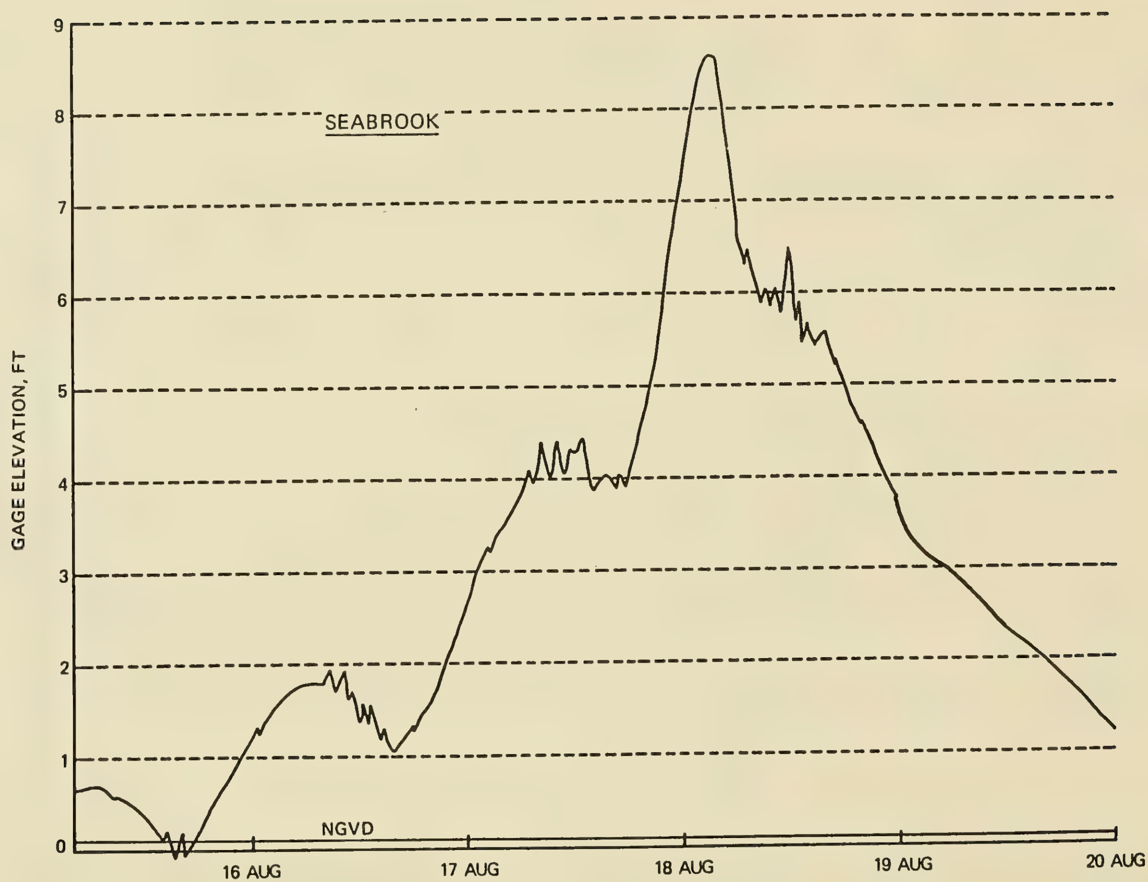


Plate 5. Hydrograph, Seabrook, Texas

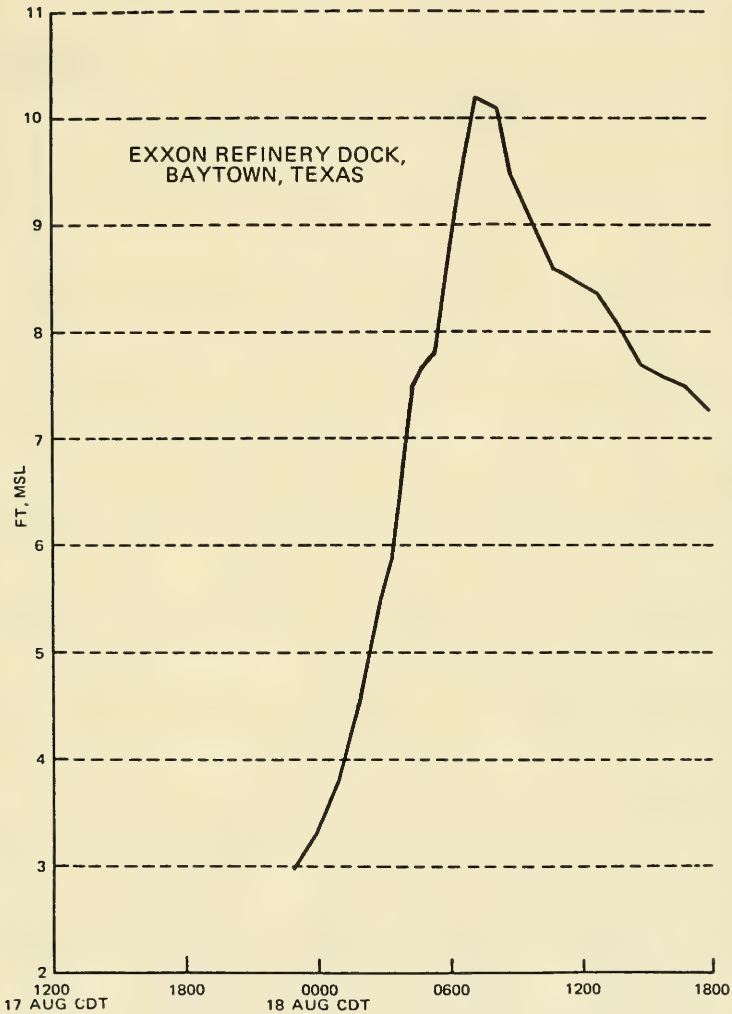


Plate 6. Hydrograph, EXXON Refinery dock, Baytown, Texas

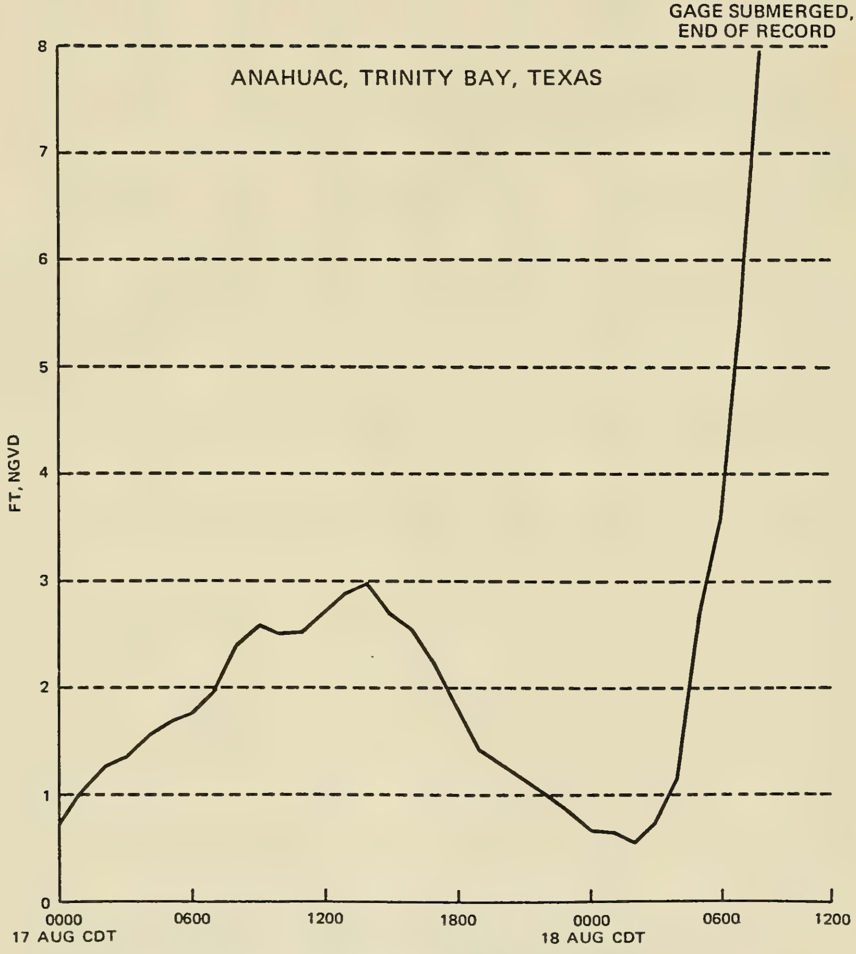


Plate 7. Hydrograph, Anahuac, Texas

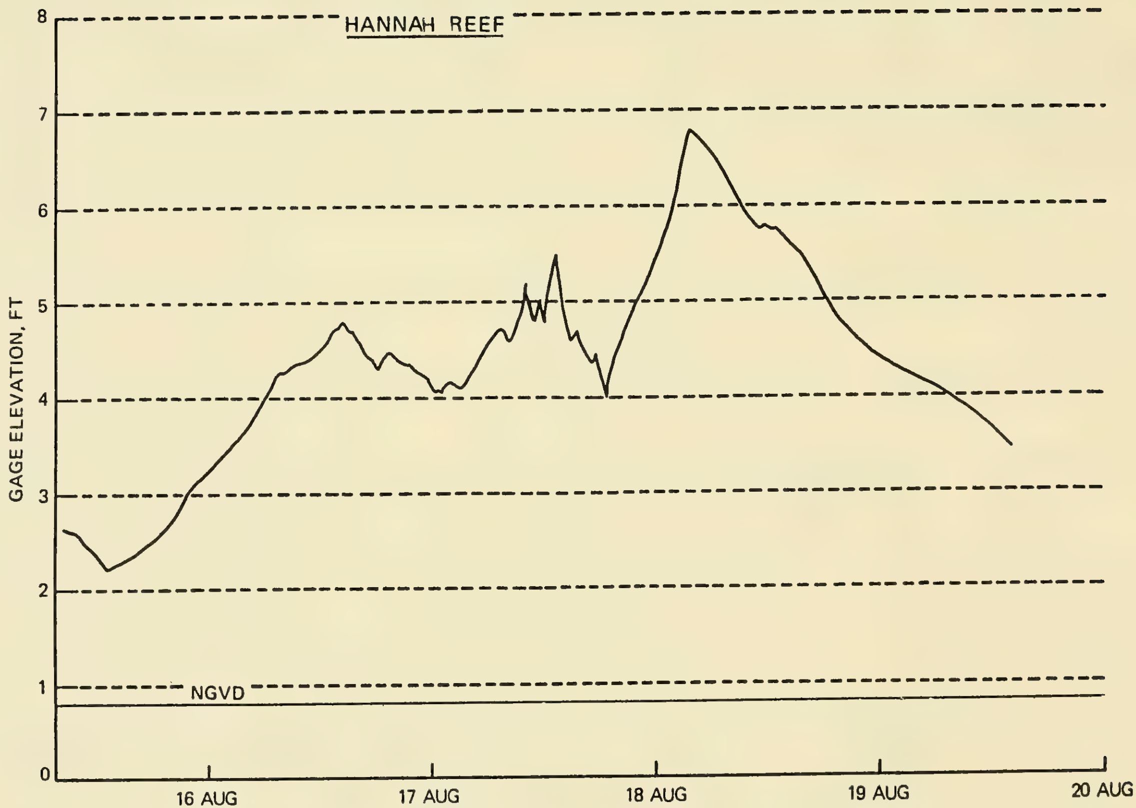


Plate 8. Hydrograph, Hannah Reef, Texas

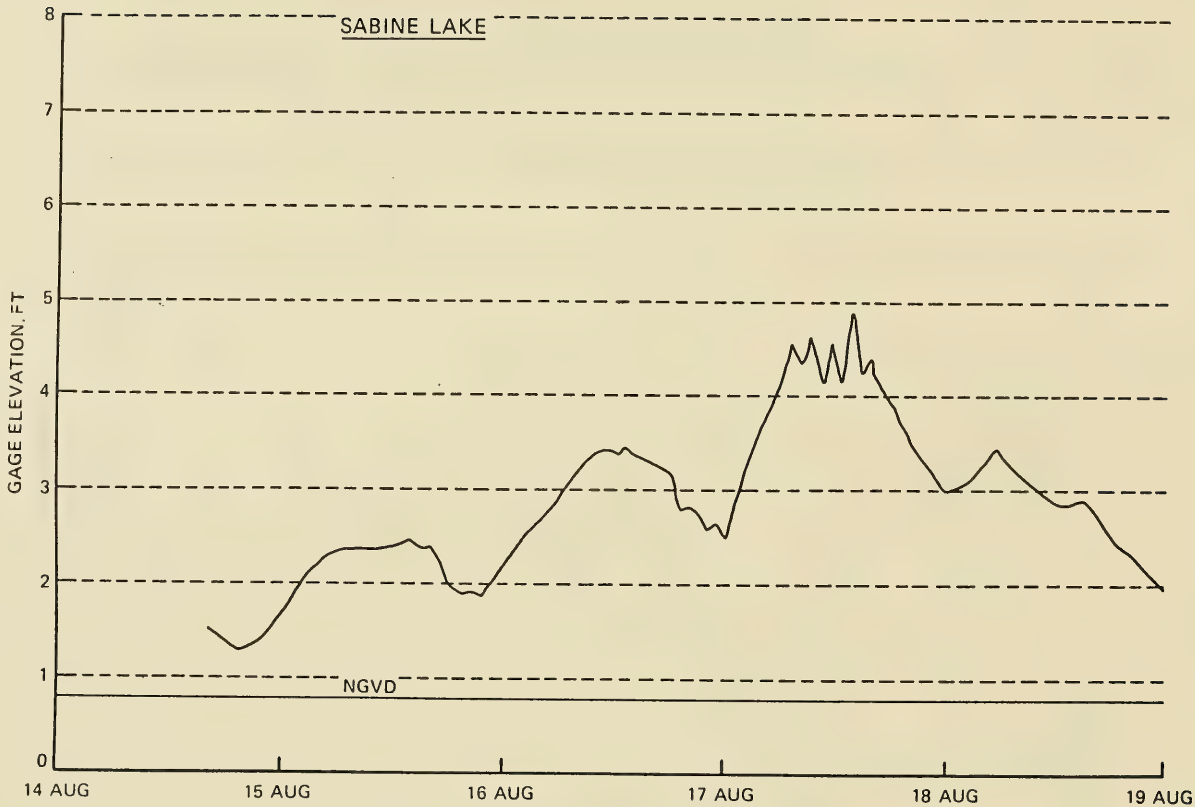


Plate 9. Hydrograph, Sabine Lake, Texas

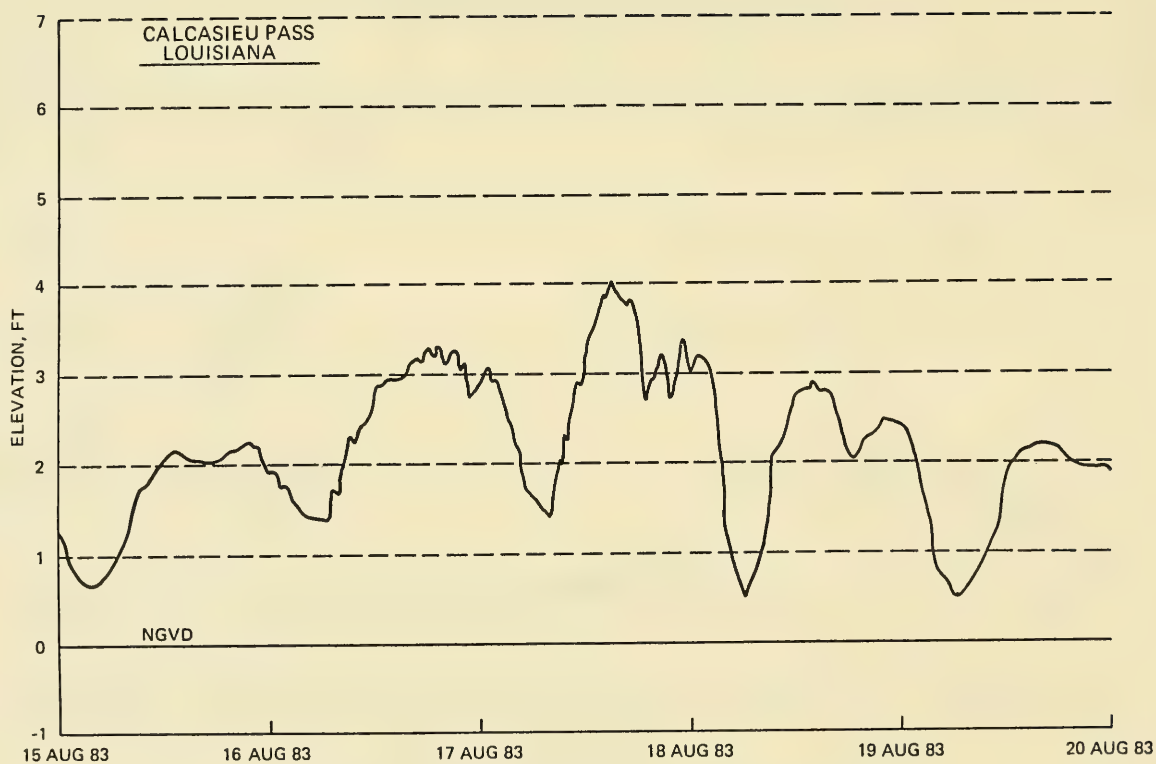


Plate 10. Hydrograph, Calcasieu Pass, Louisiana

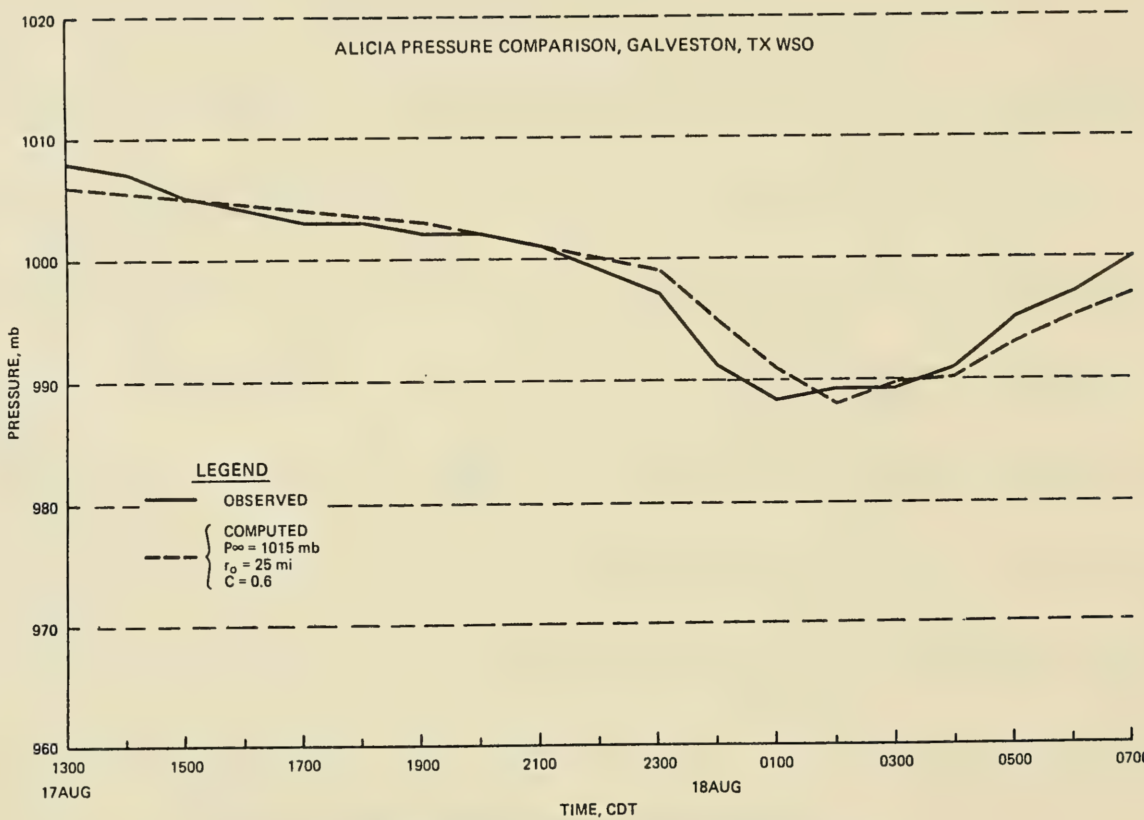


Plate 11. Comparison of observed and computed pressures for Galveston Weather Service Office location

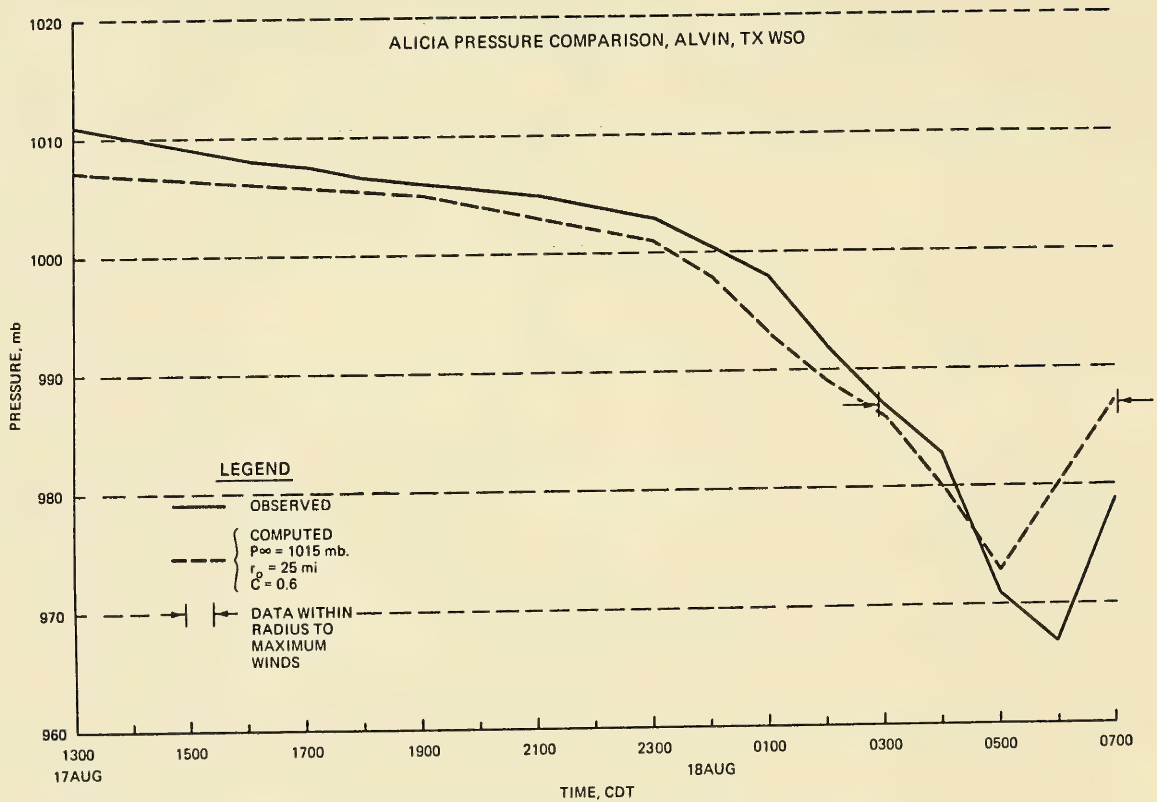


Plate 12. Comparison of observed and computed pressures for Alvin Weather Service Office location

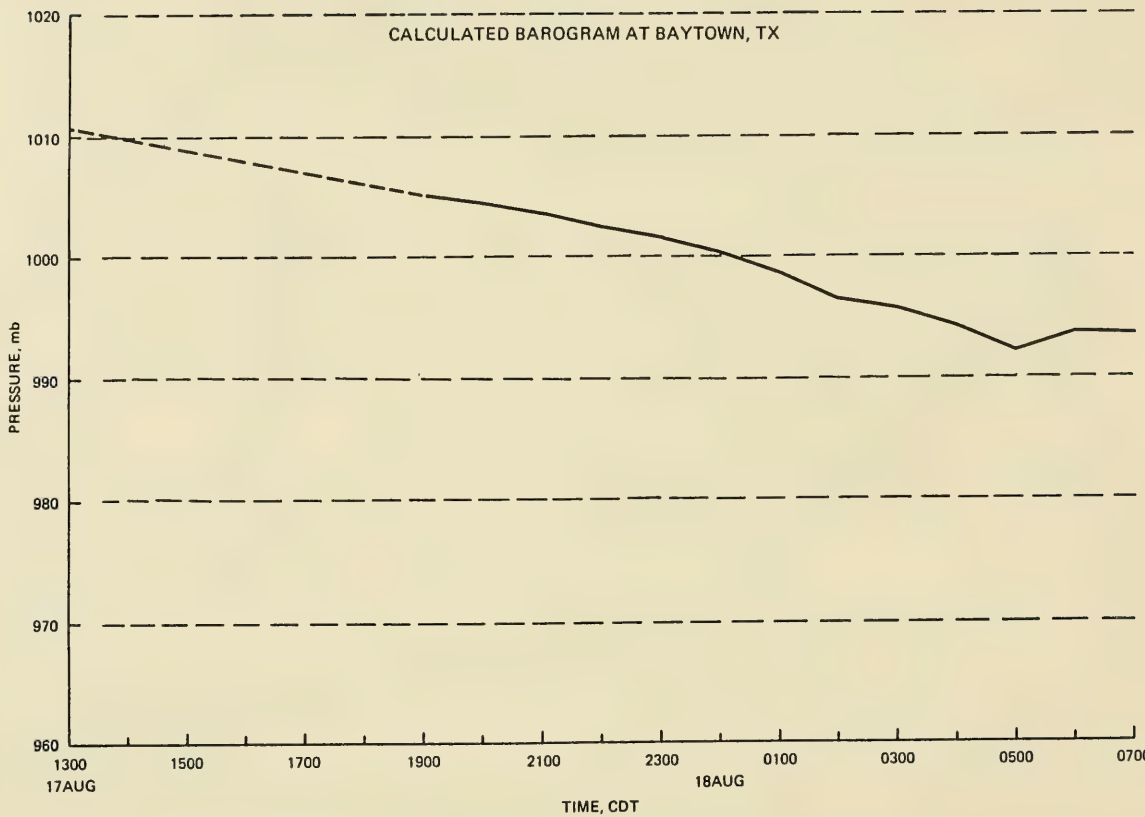


Plate 13. Calculated barogram at T-14 location, Baytown, Texas

Plate 14. Corrected and uncorrected hydrographs, T-14 location, Baytown, Texas

Plate 15. Significant wave height during passage of Alicia, Shell platform Vermillion 22

Plate 16. Significant wave height during passage of Alicia, Shell platform Eugene Island

Plate 17. Significant wave height during passage of Alicia, Shell platform Bay Marchand

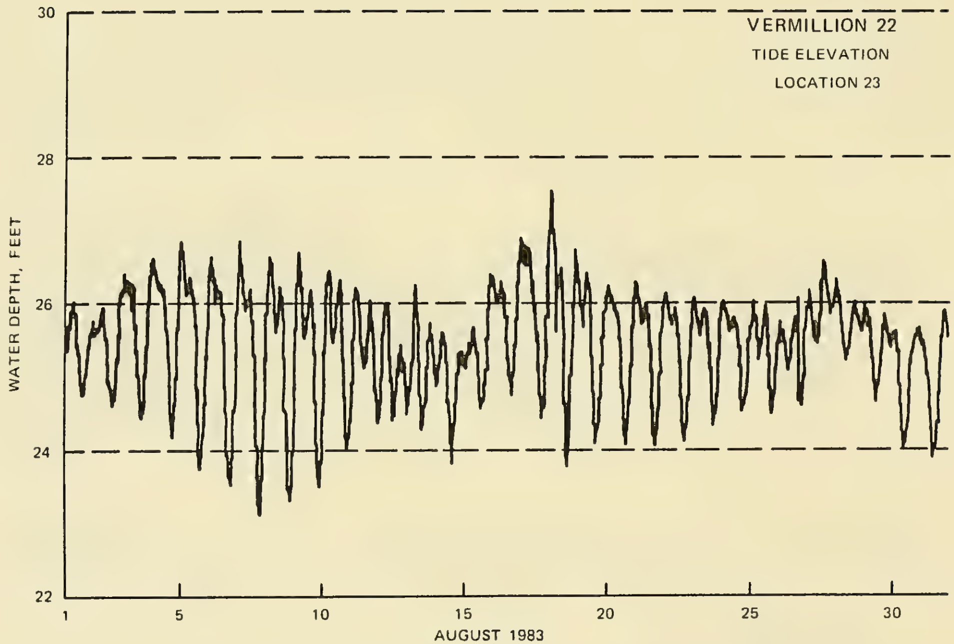


Plate 18. Tide record, Shell platform Vermillion 22

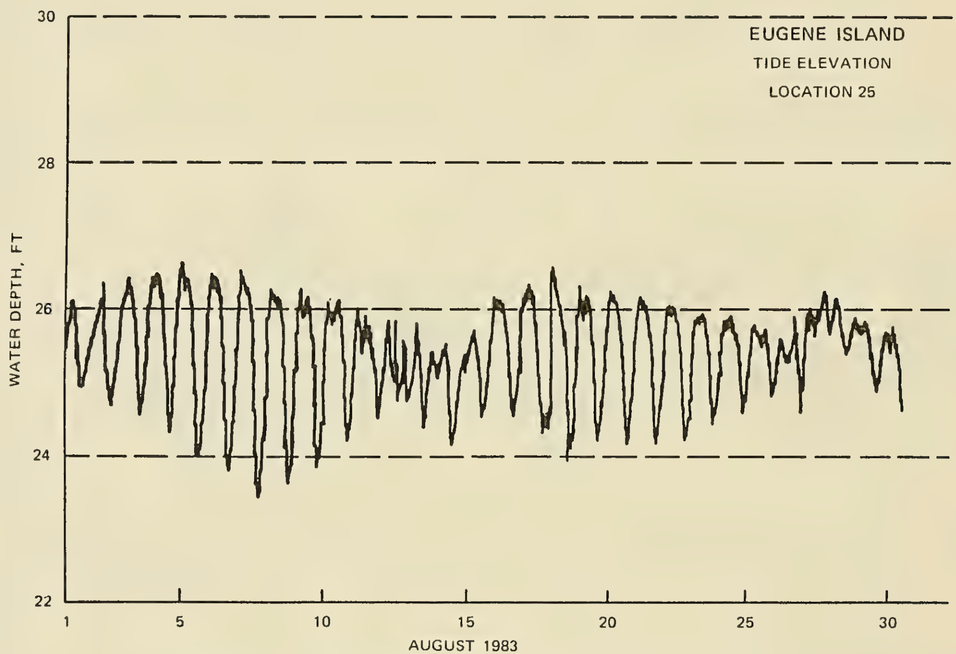


Plate 19. Tide record, Shell platform Eugene Island

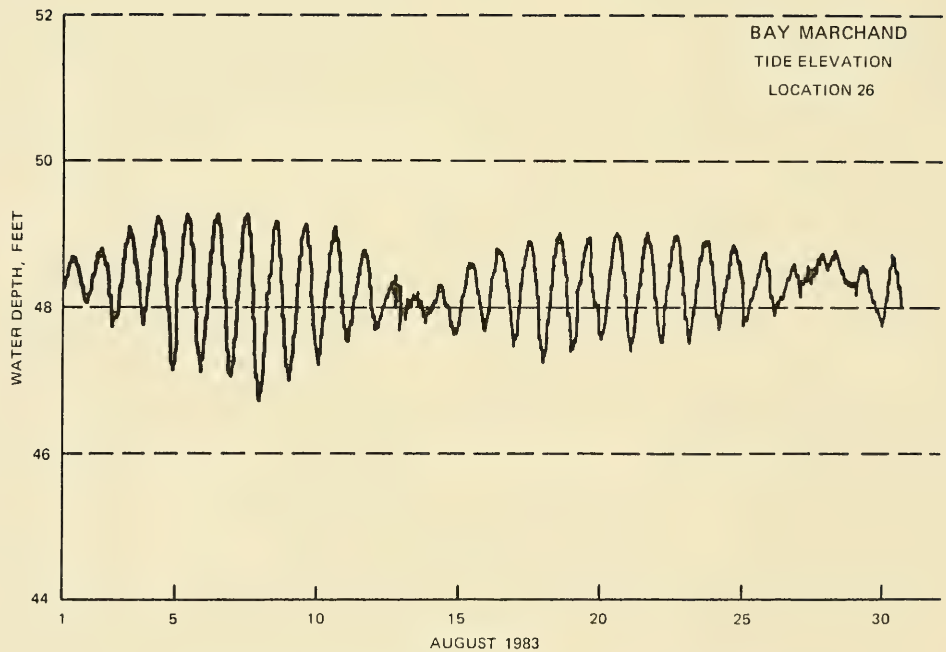
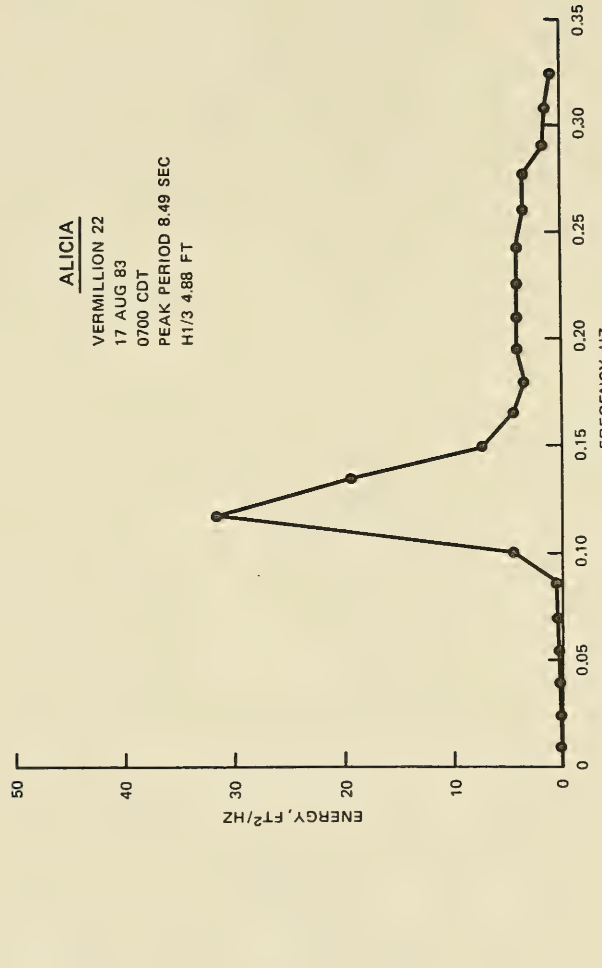


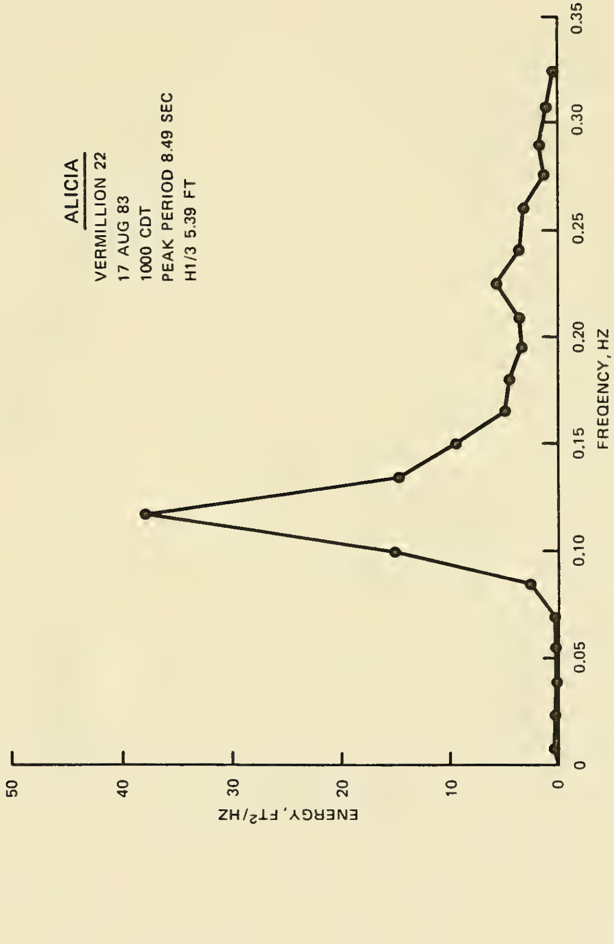
Plate 20. Tide record, Shell platform Bay Marchand

APPENDIX A: WAVE SPECTRAL PLOTS OBTAINED DURING PASSAGE OF HURRICANE ALICIA

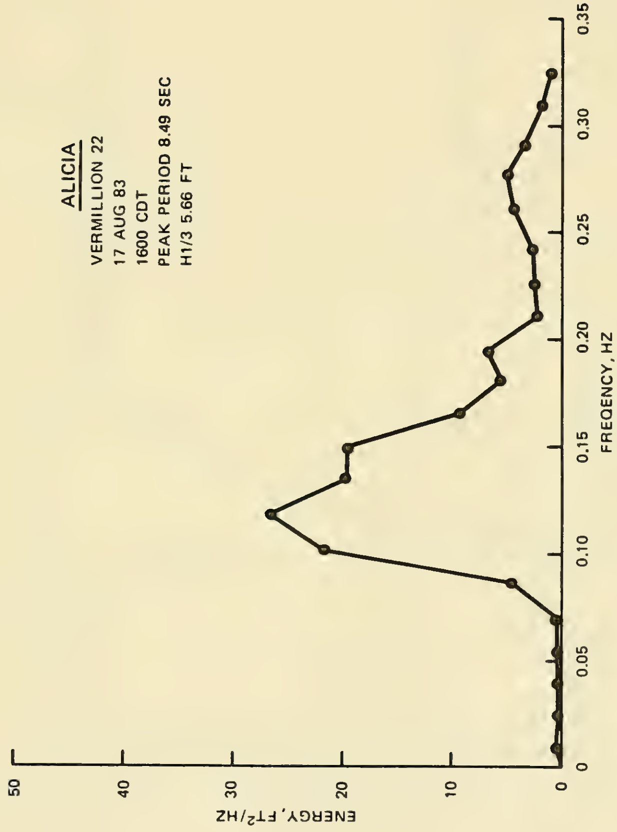
1. A series of wave spectral plots obtained at the Shell Oil Company platforms Vermillion 22, Eugene Island 100, and Bay Marchand 2.Q during passage of hurricane Alicia are included in this appendix.

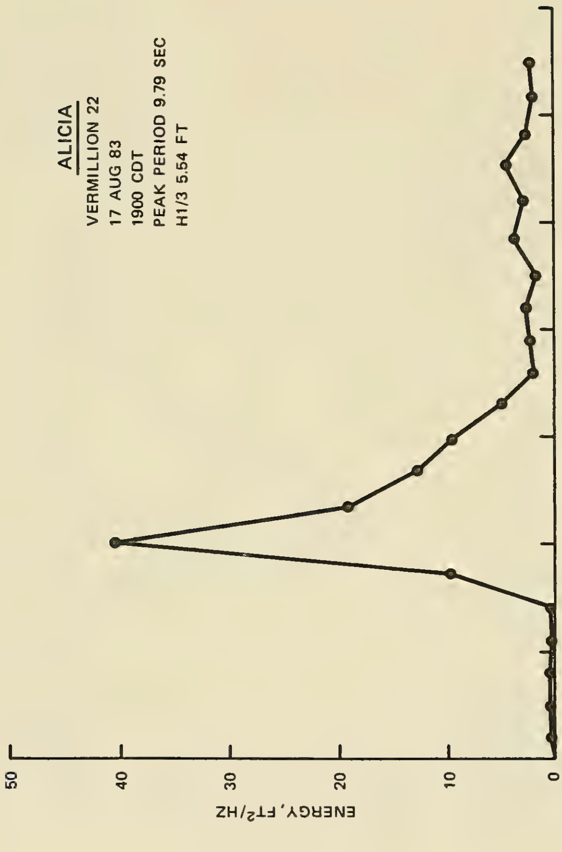
2. The data were obtained using a subsurface pressure sensor hardwired to self-powered, self-contained, internally recording data loggers. Wave records were obtained at 3-hr intervals and consisted of 1024 data points sampled at 1 Hz. The pressure data were analyzed by means of a Fast Fourier Transform and each spectral component was compensated for pressure attenuation using linear wave theory. Components of the resulting periodigram were block-averaged to produce spectra with 32 equivalent degrees of freedom.

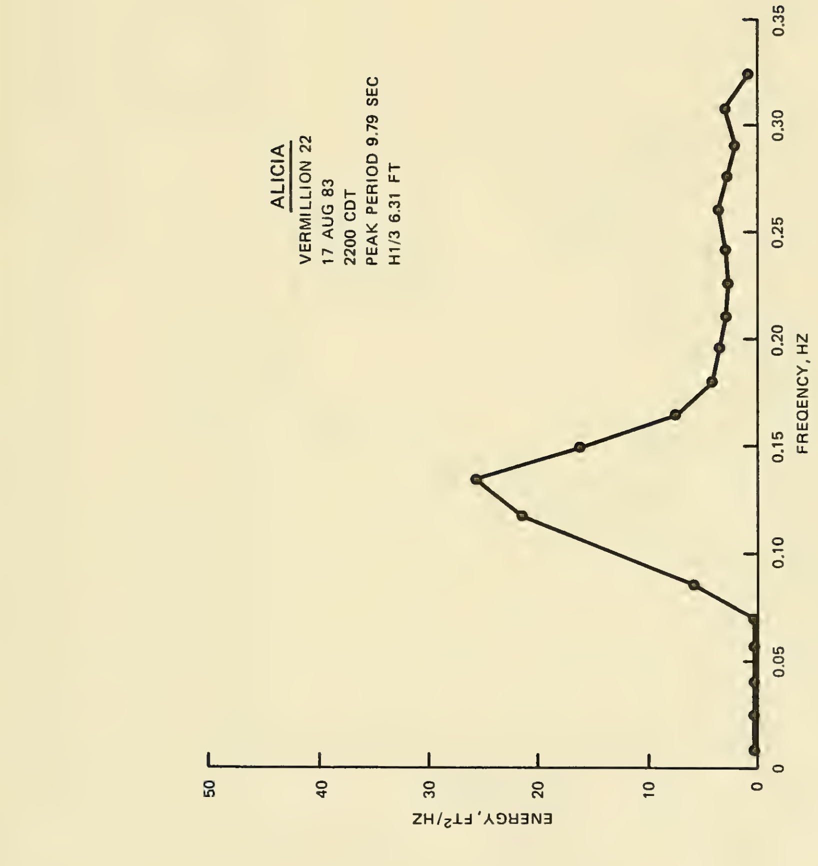

ALICIA
VERMILLION 22
17 AUG 83
0700 CDT
PEAK PERIOD 8.49 SEC
H1/3 4.88 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
FREQENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35

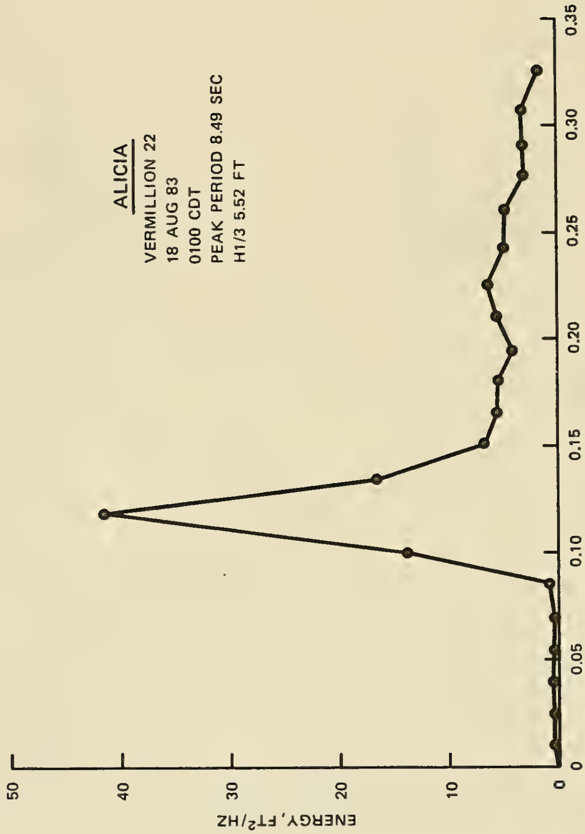

ALICIA
VERMILLION 22
17 AUG 83
1000 CDT
PEAK PERIOD 8.49 SEC
H1/3 5.39 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
FREQENCY, HZ

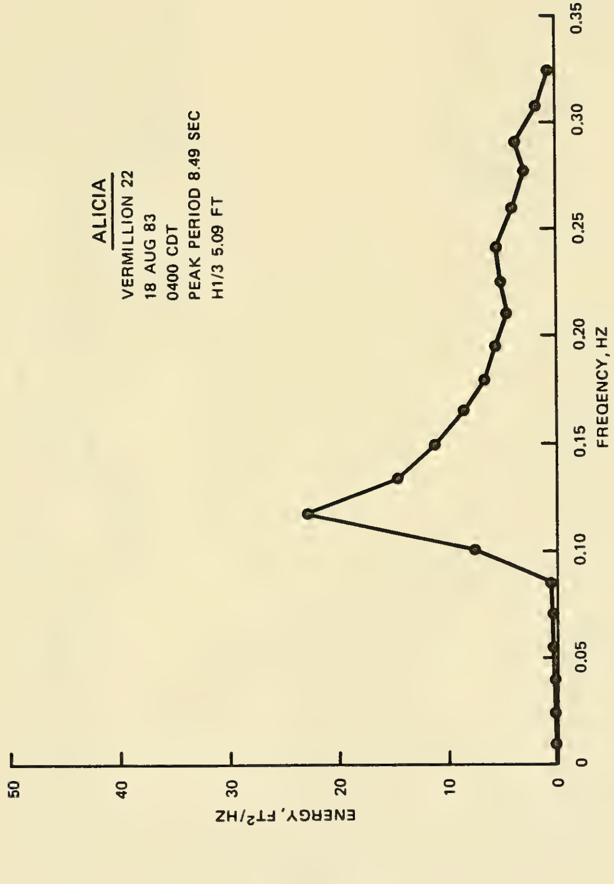

ALICIA
VERMILLION 22
17 AUG 83
1300 CDT
PEAK PERIOD 8.49 SEC
H1/3 6.29 FT
ENERGY, FT^2/HZ
0
10
20
30
40
50
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
FREQENCY, HZ


ALICIA
VERMILLION 22
17 AUG 83
1600 CDT
PEAK PERIOD 8.49 SEC
H1/3 5.66 FT
ENERGY, FT2/HZ
FREQENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35

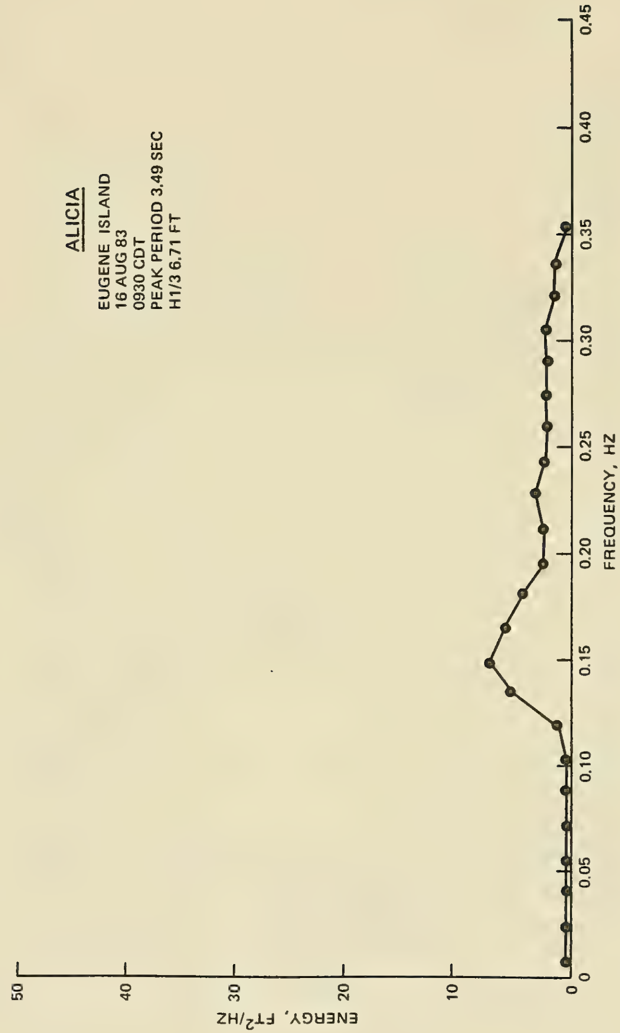

ALICIA
VERMILLION 22
17 AUG 83
1900 CDT
PEAK PERIOD 9.79 SEC
H1/3 5.54 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
FREQENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35

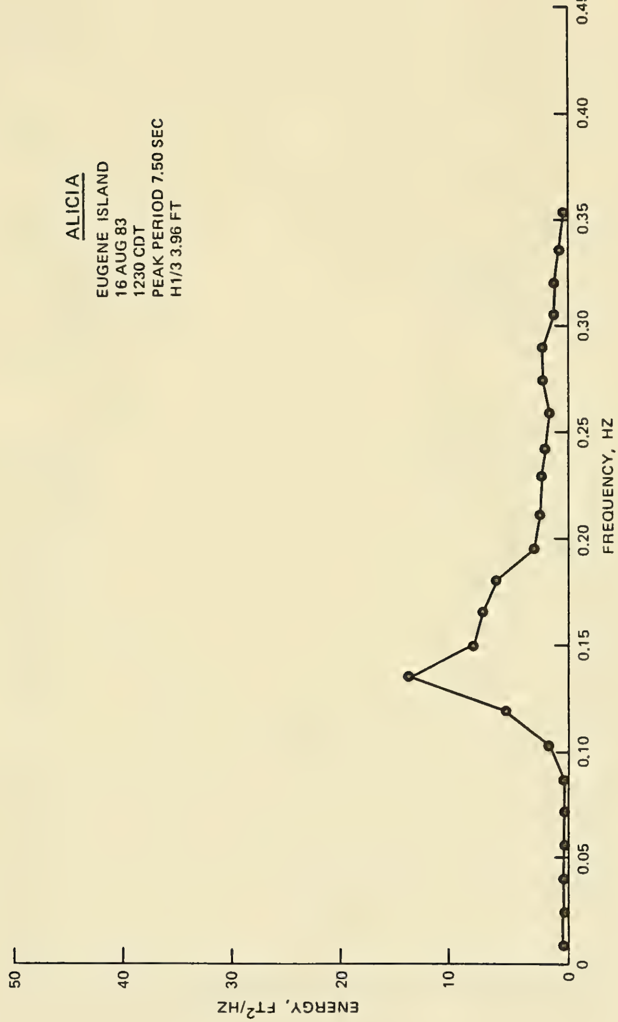

ALICIA
VERMILLION 22
17 AUG 83
2200 CDT
PEAK PERIOD 9.79 SEC
H1/3 6.31 FT
ENERGY, FT^2/HZ
0
10
20
30
40
50
FREQENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35


ALICIA
VERMILLION 22
18 AUG 83
0100 CDT
PEAK PERIOD 8.49 SEC
H1/3 5.52 FT
ENERGY, FT2/HZ
FREQENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35

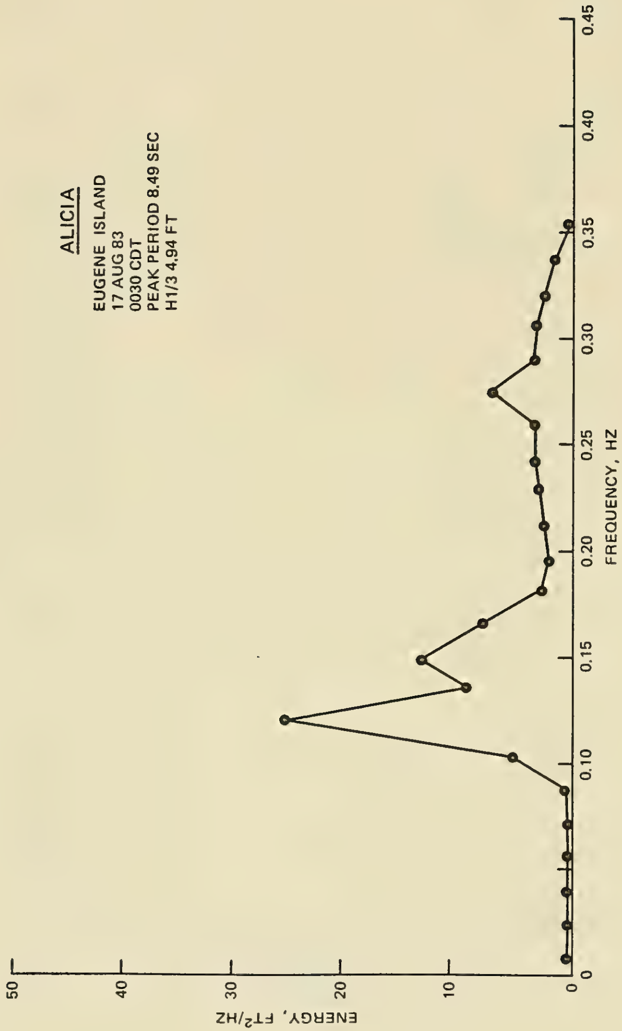


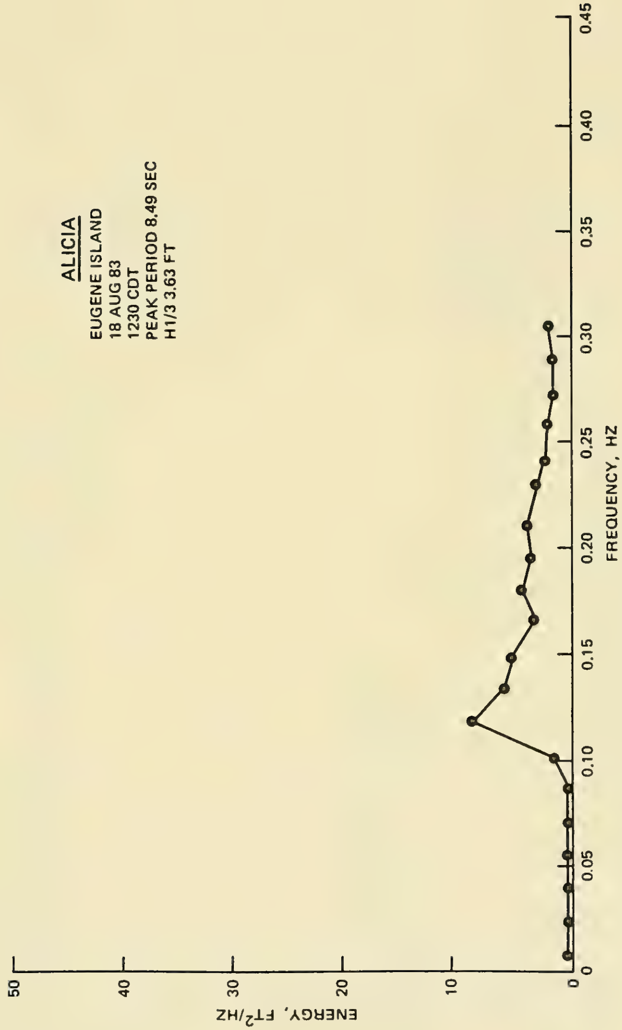
ALICIA
VERMILLION 22
18 AUG 83
0400 CDT
PEAK PERIOD 8.49 SEC
H1/3 5.09 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
FREQENCY, HZ

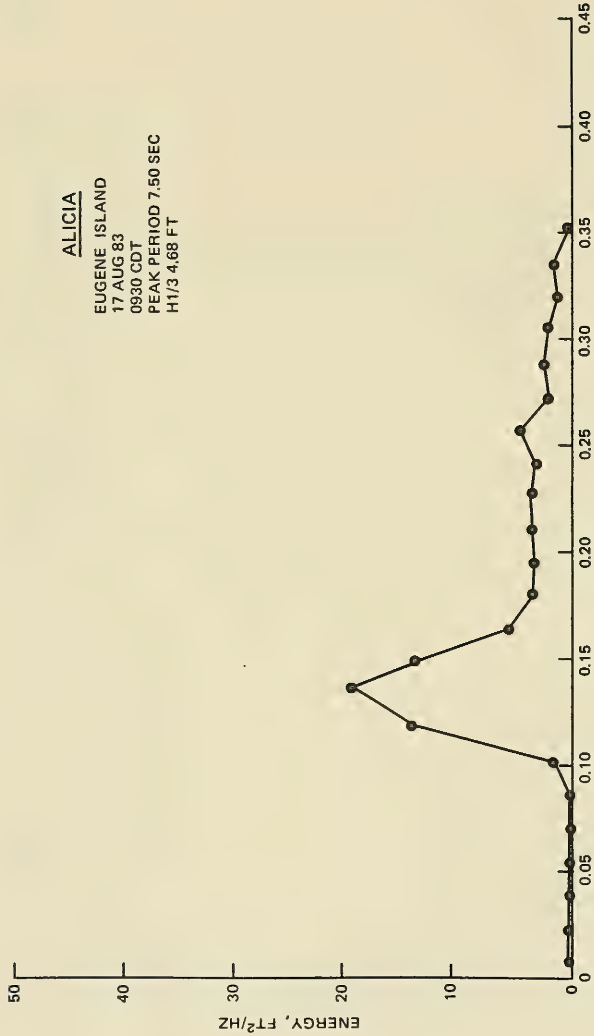

ALICIA
EUGENE ISLAND
16 AUG 83
0930 CDT
PEAK PERIOD 3.49 SEC
H1/3 6.71 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

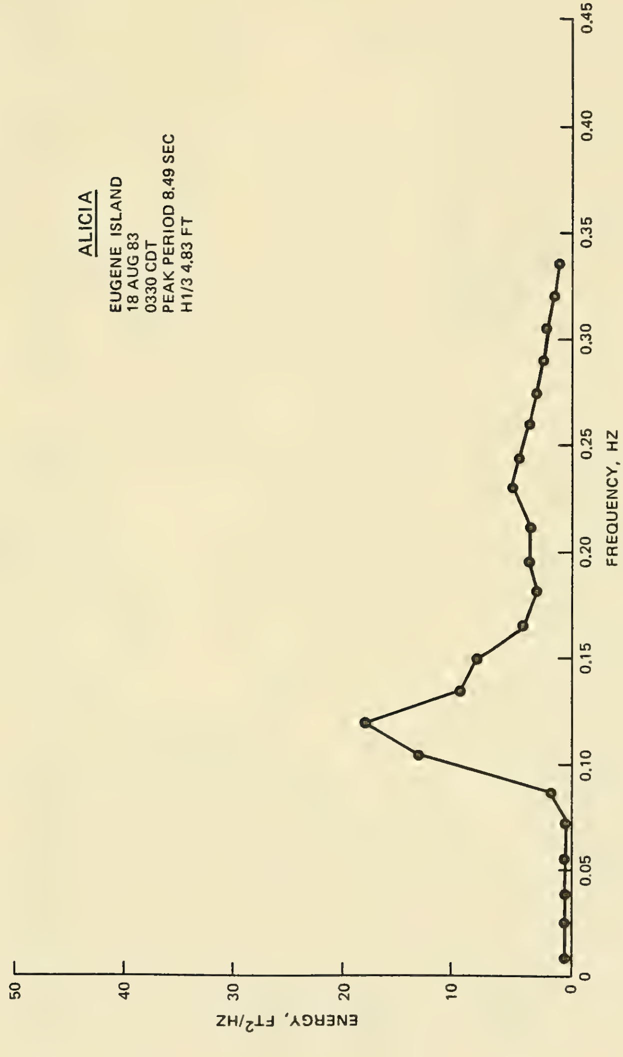


ALICIA
EUGENE ISLAND
16 AUG 83
1230 CDT
PEAK PERIOD 7.50 SEC
H1/3 3.96 FT
ENERGY, FT2/HZ
FREQUENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

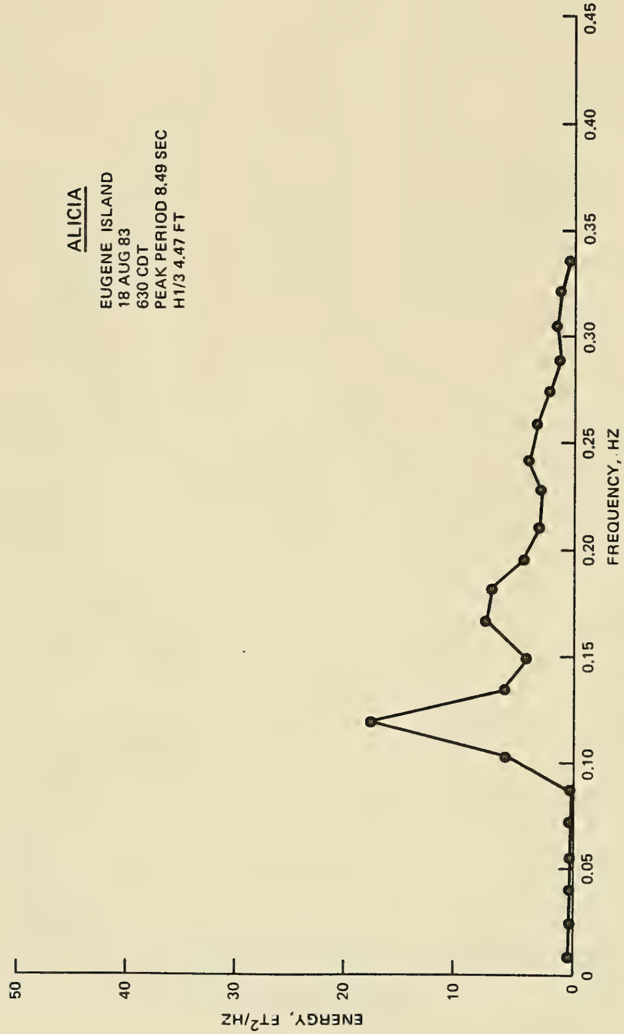

ALICIA
EUGENE ISLAND
17 AUG 83
0030 CDT
PEAK PERIOD 8.49 SEC
H1/3 4.94 FT
ENERGY, FT²/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

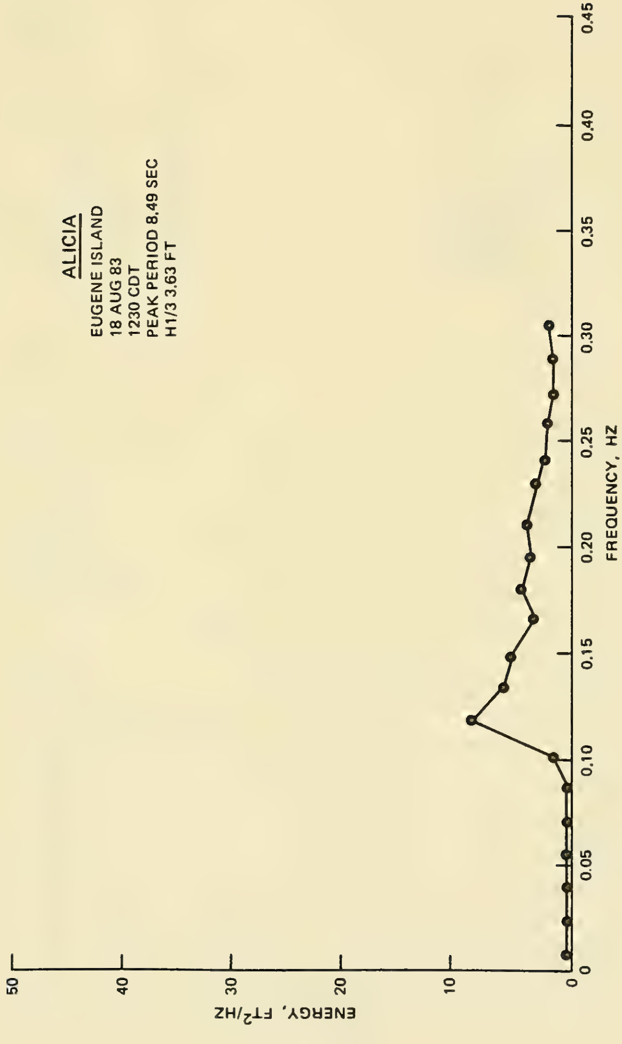

ALICIA
EUGENE ISLAND
18 AUG 83
1230 CDT
PEAK PERIOD 8.49 SEC
H1/3 3.63 FT
ENERGY, FT^2/HZ
FREQUENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

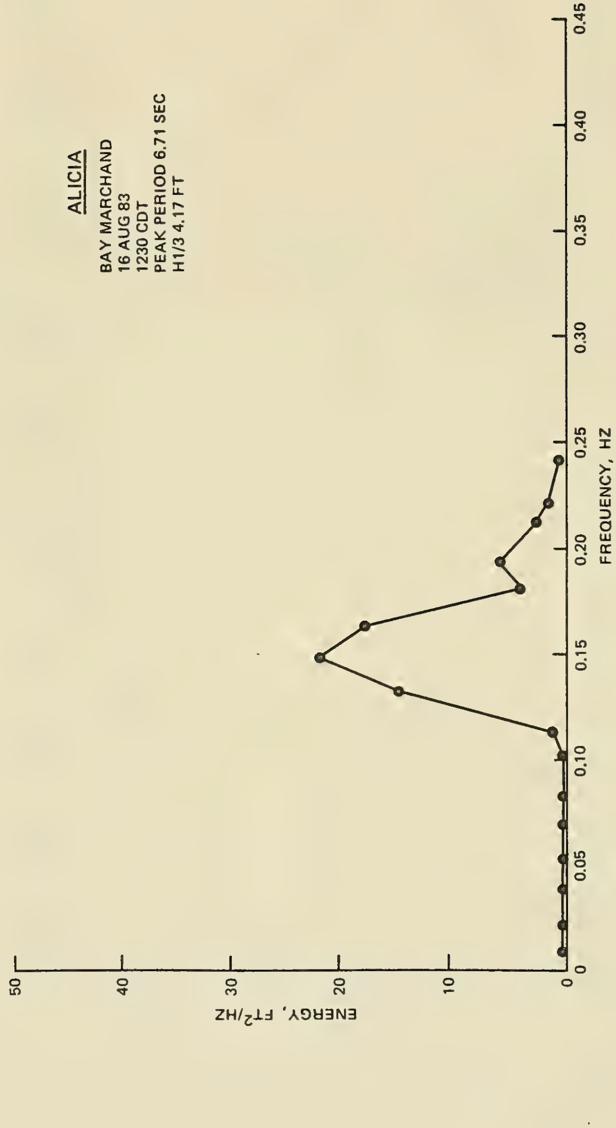

ALICIA
EUGENE ISLAND
17 AUG 83
0930 CDT
PEAK PERIOD 7.50 SEC
H1/3 4.68 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
FREQUENCY, HZ

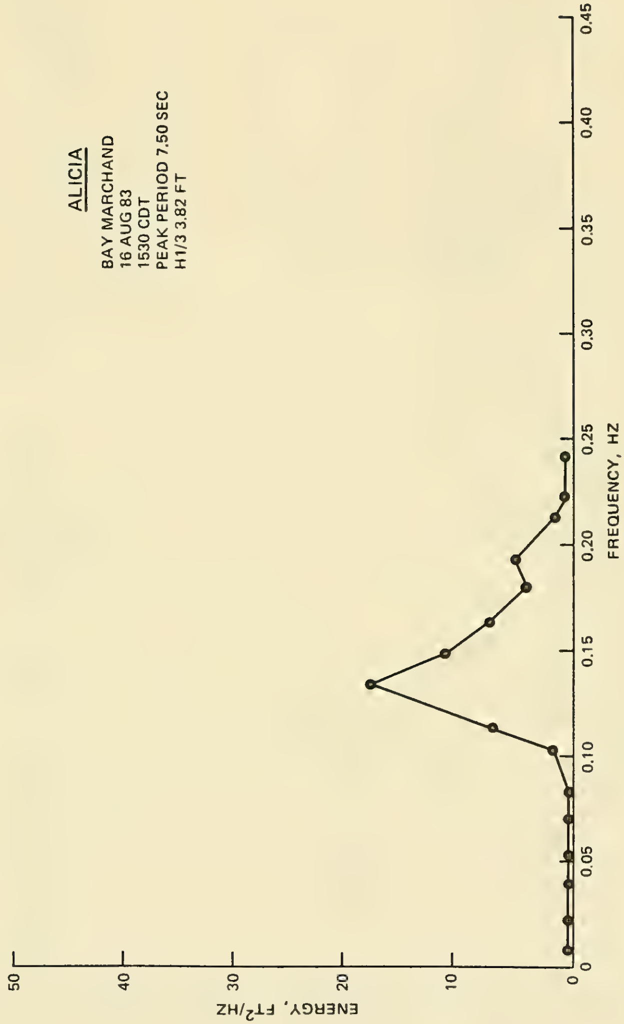


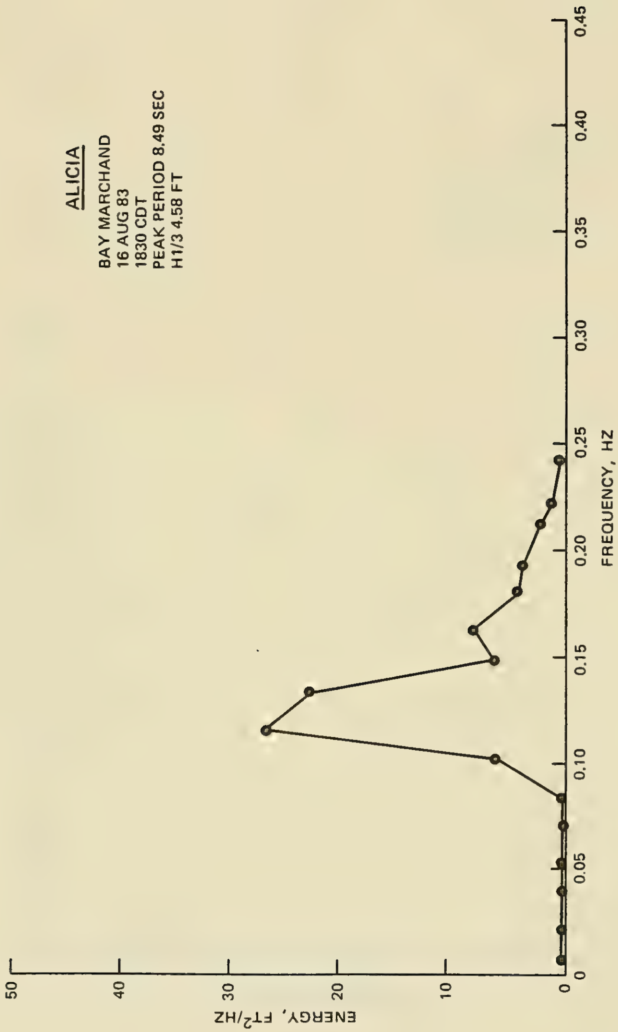
ALICIA
EUGENE ISLAND
18 AUG 83
0330 CDT
PEAK PERIOD 8.49 SEC
H1/3 4.83 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

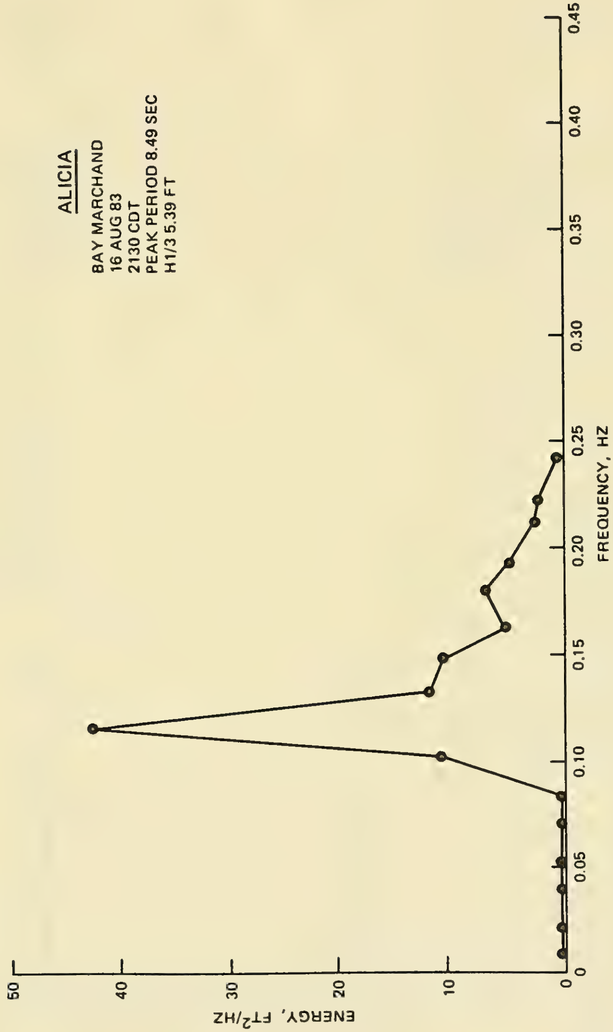

ALICIA
EUGENE ISLAND
18 AUG 83
630 CDT
PEAK PERIOD 8.49 SEC
H1/3 4.47 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

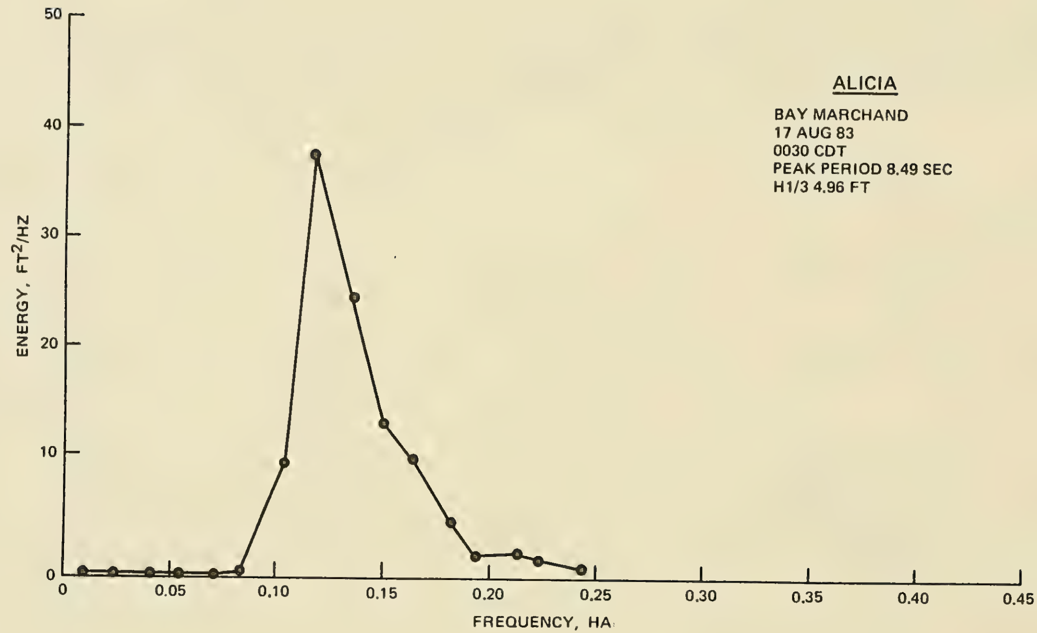

ALICIA
EUGENE ISLAND
18 AUG 83
1230 CDT
PEAK PERIOD 8.49 SEC
H1/3 3.63 FT
ENERGY, FT²/HZ
FREQUENCY, HZ
0
10
20
30
40
50
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

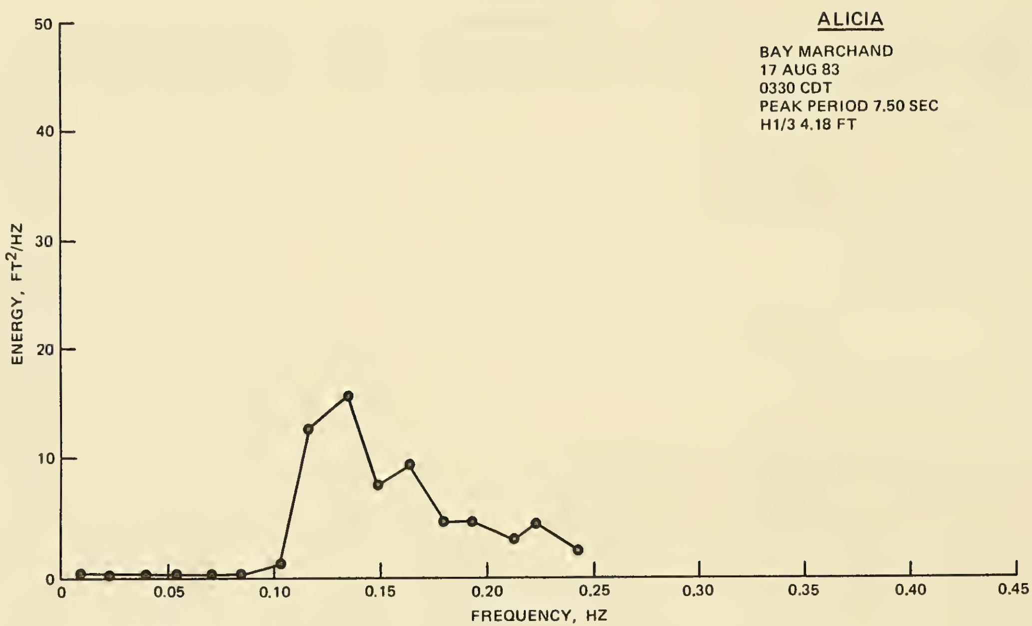

ALICIA
BAY MARCHAND
16 AUG 83
1230 CDT
PEAK PERIOD 6.71 SEC
H1/3 4.17 FT
ENERGY, FT^2/HZ
0
10
20
30
40
50
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
FREQUENCY, HZ


ALICIA
BAY MARCHAND
16 AUG 83
1530 CDT
PEAK PERIOD 7.50 SEC
H1/3 3.82 FT
ENERGY, FT^2/HZ
FREQUENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

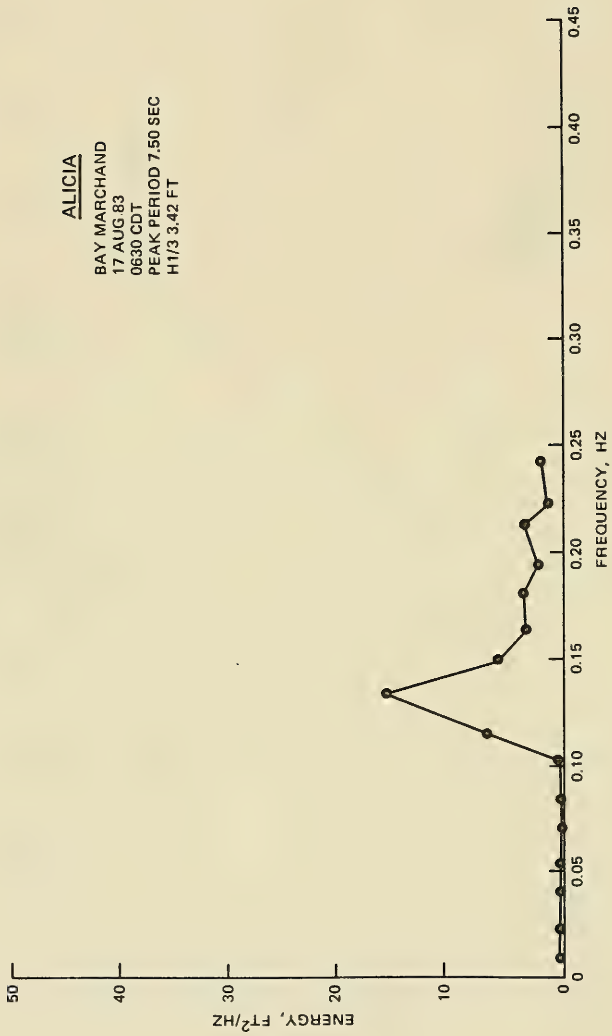

ALICIA
BAY MARCHAND
16 AUG 83
1830 CDT
PEAK PERIOD 8.49 SEC
H1/3 4.58 FT
ENERGY, FT²/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

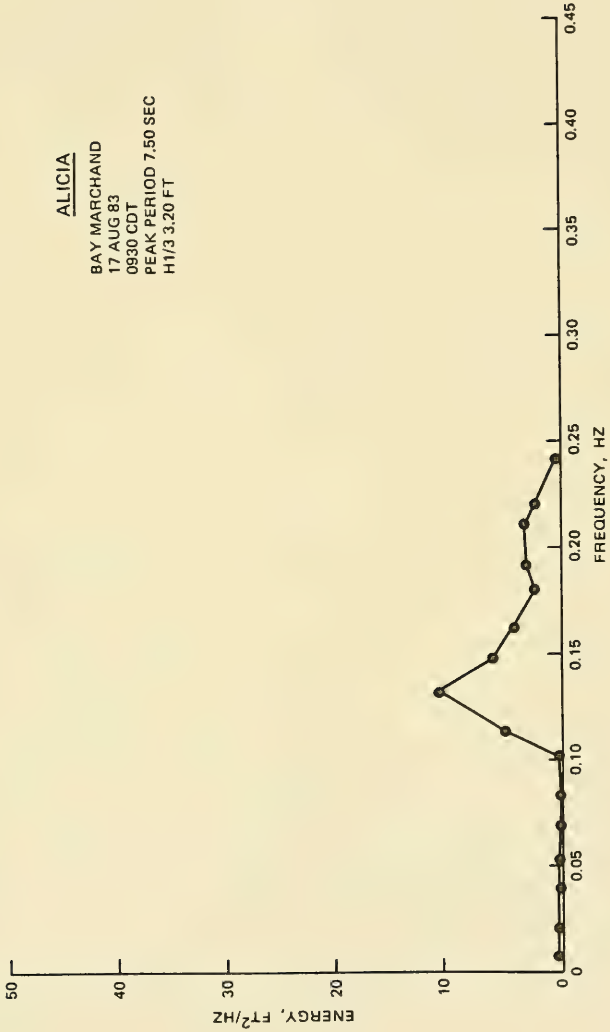

ALICIA
BAY MARCHAND
16 AUG 83
2130 CDT
PEAK PERIOD 8.49 SEC
H1/3 5.39 FT
ENERGY, FT^2/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45


ALICIA
BAY MARCHAND
17 AUG 83
0030 CDT
PEAK PERIOD 8.49 SEC
H1/3 4.96 FT
ENERGY, FT2/HZ
50
40
30
20
10
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
FREQUENCY, HA



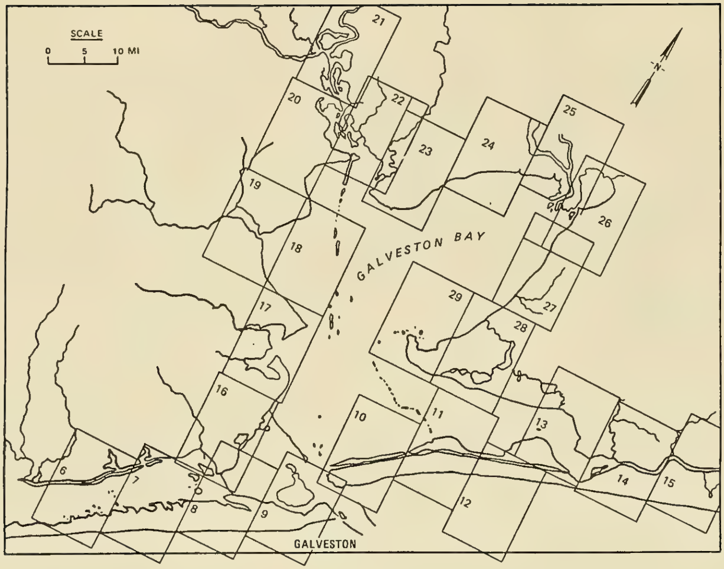
ALICIA
BAY MARCHAND
17 AUG 83
0330 CDT
PEAK PERIOD 7.50 SEC
H1/3 4.18 FT
ENERGY, FT2/HZ
FREQUENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

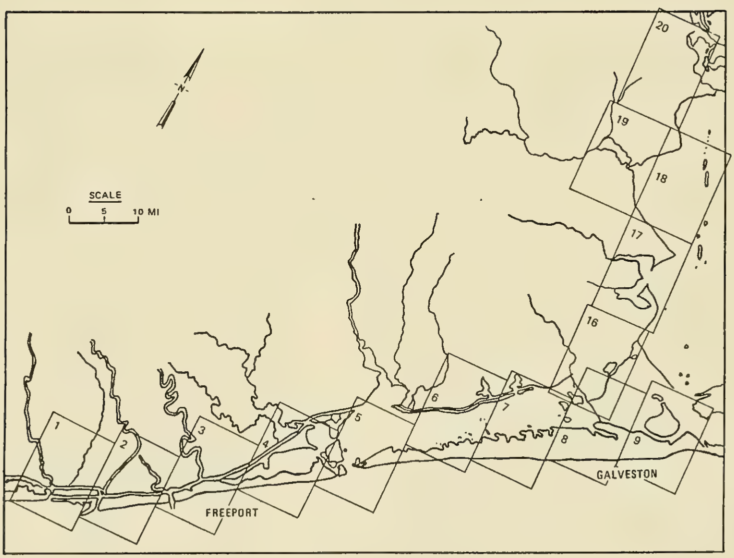

ALICIA
BAY MARCHAND
17 AUG 83
0630 CDT
PEAK PERIOD 7.50 SEC
H1/3 3.42 FT
ENERGY, FT2/HZ
FREQUENCY, HZ
0
10
20
30
40
50
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45


ALICIA
BAY MARCHAND
17 AUG 83
0930 CDT
PEAK PERIOD 7.50 SEC
H1/3 3.20 FT
ENERGY, FT2/HZ
0
10
20
30
40
50
FREQUENCY, HZ
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45

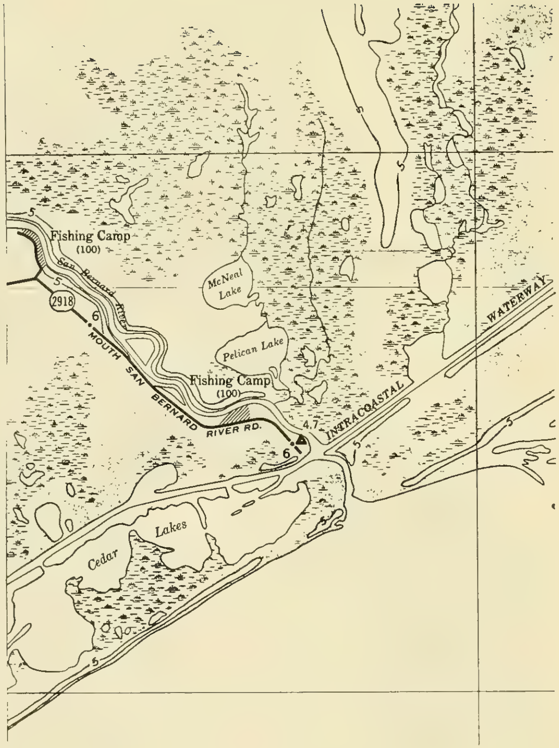
APPENDIX B: HIGH WATER CONTOUR MAPS

The series of contour maps in this Appendix are segments of the National Ocean Service Storm Evacuation maps for Houston, Anahuac, Winnie, Galveston, Alvin, and Freeport, Texas. Each segment covers an area approximately 6 miles wide and 8 miles long and has a contour interval of 5 ft. High water marks, surveyed by the Galveston District, CE, are plotted on the maps. Not all maps contain a high water mark but are included for reasons of continuity. Each high water mark, written in feet above NGVD, is represented by a ▲ on the contour maps.

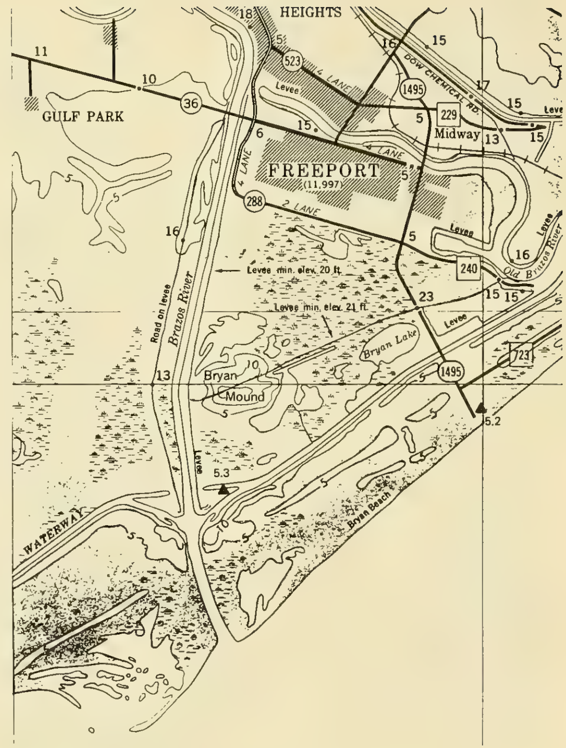




Index To High Water Contour Maps
Segments 1-29



Segment 1



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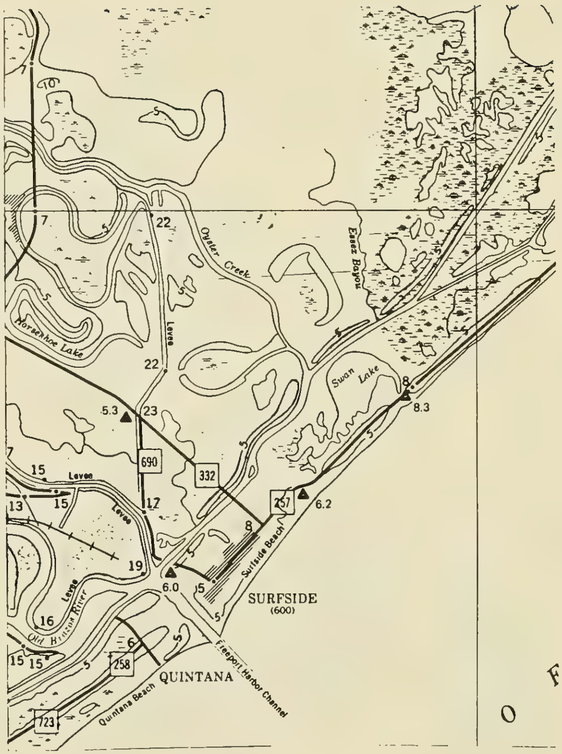

Segment 3

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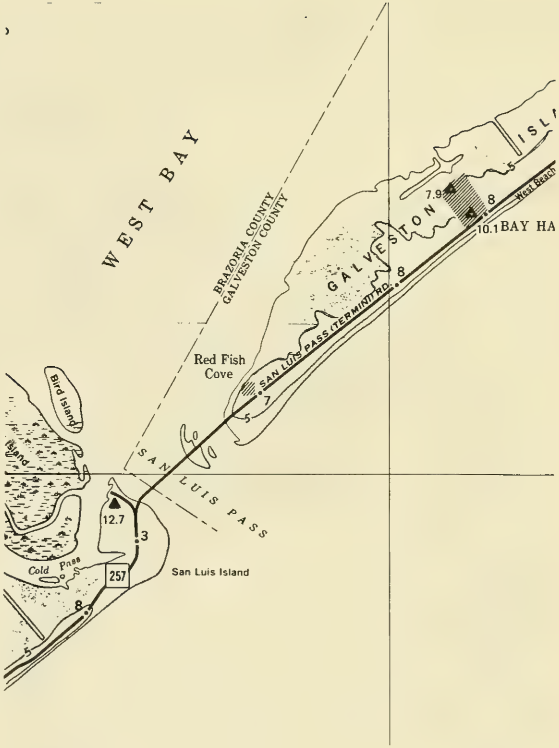

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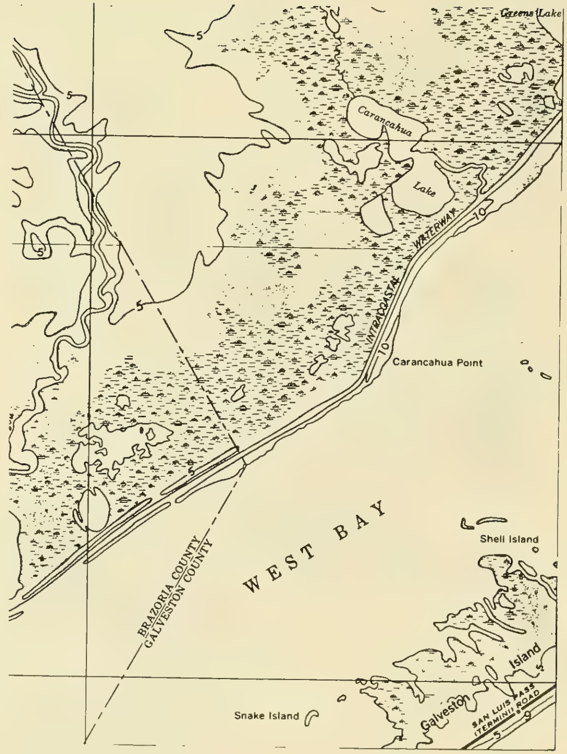

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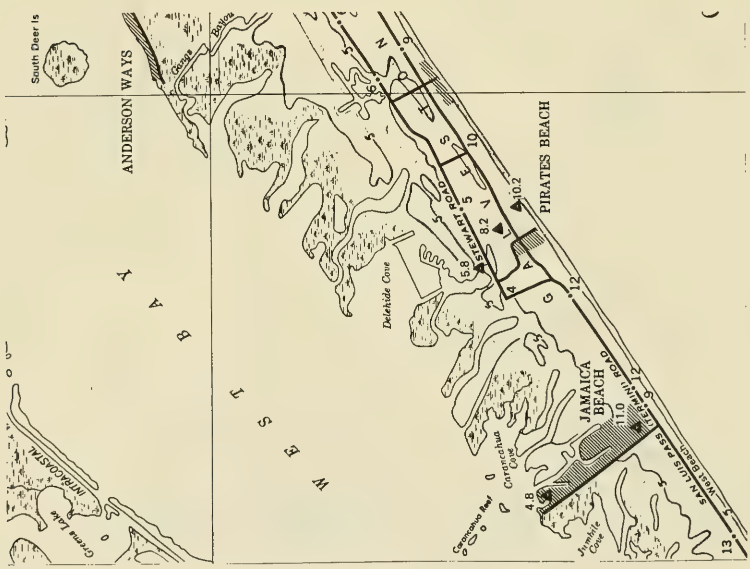

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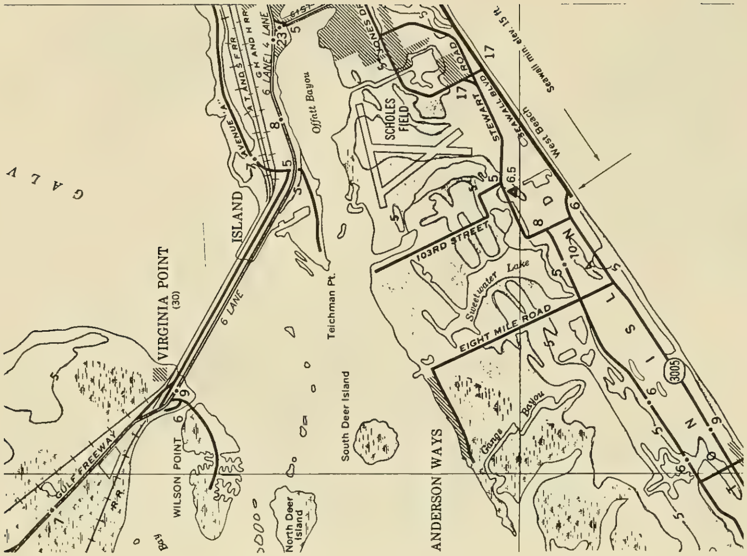

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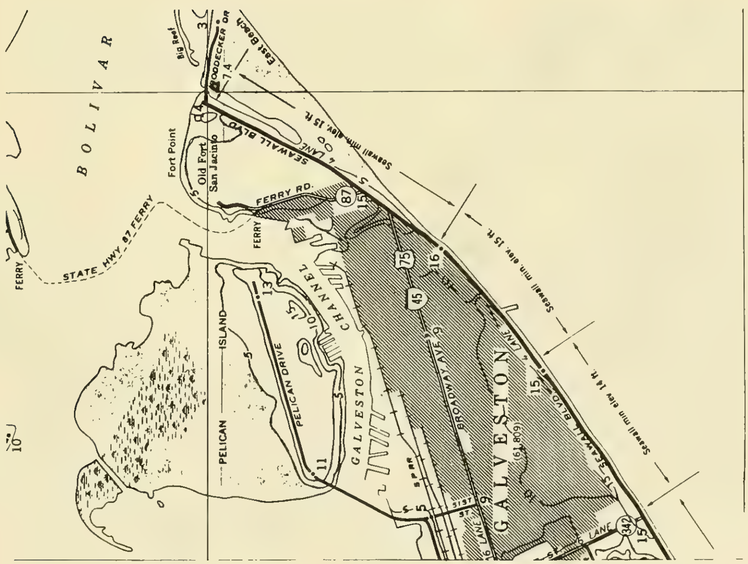

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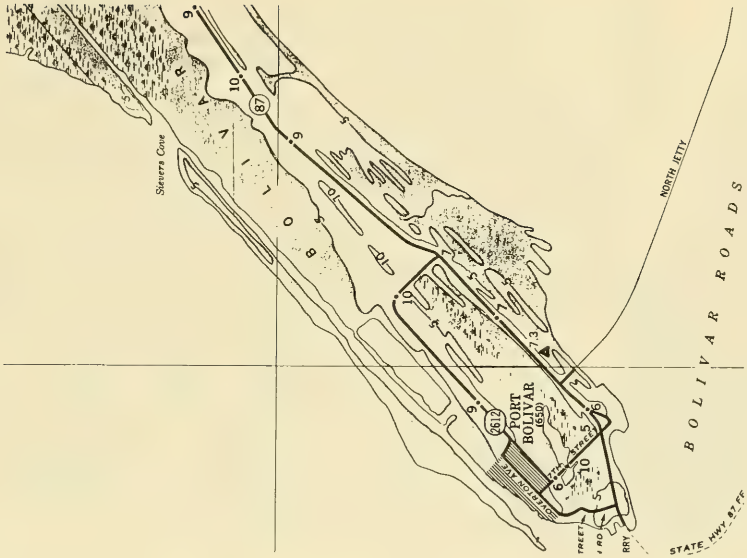

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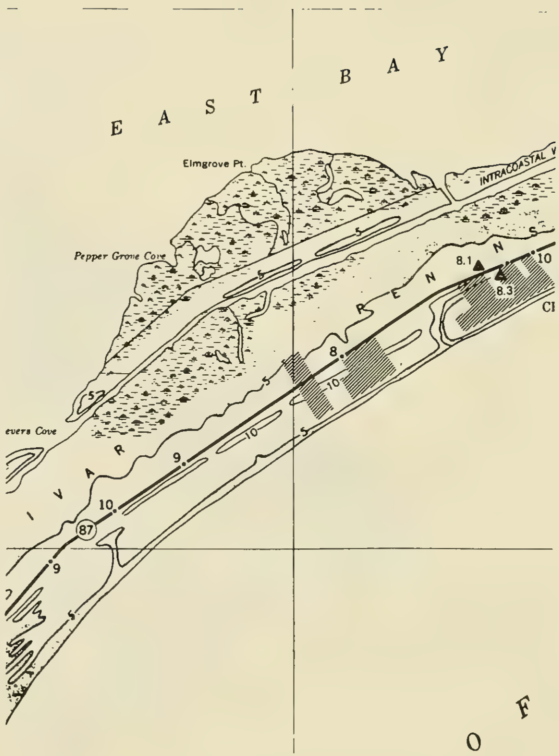

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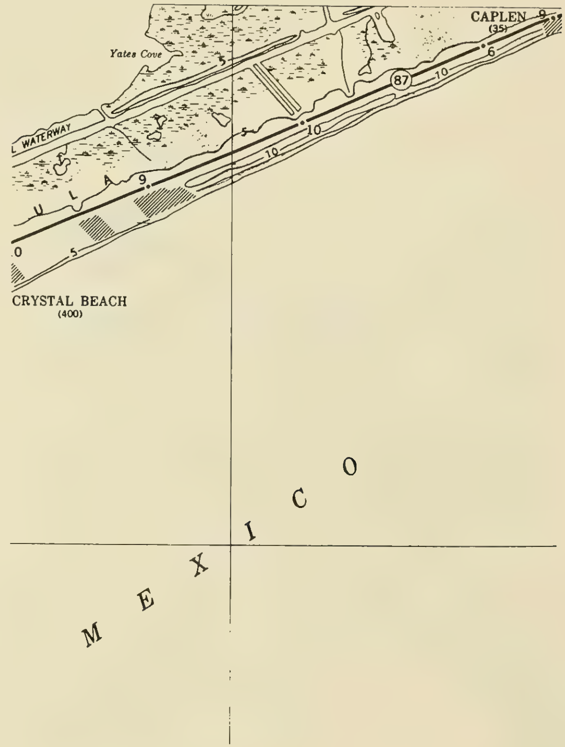

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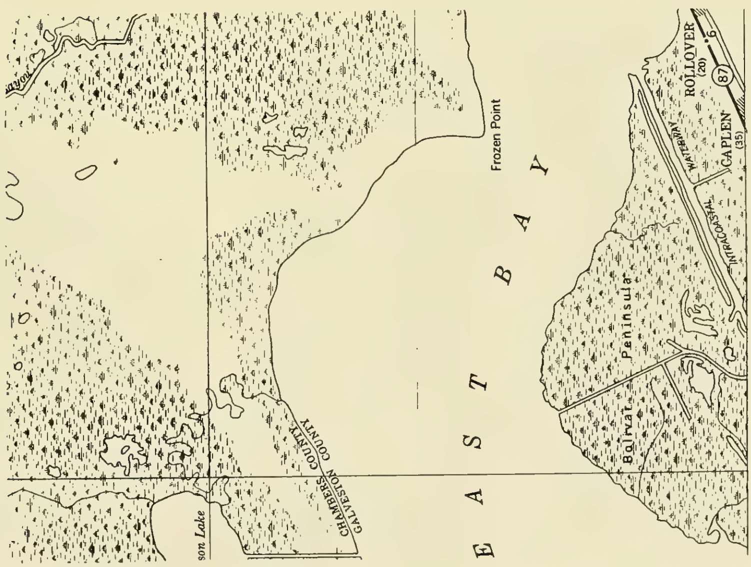

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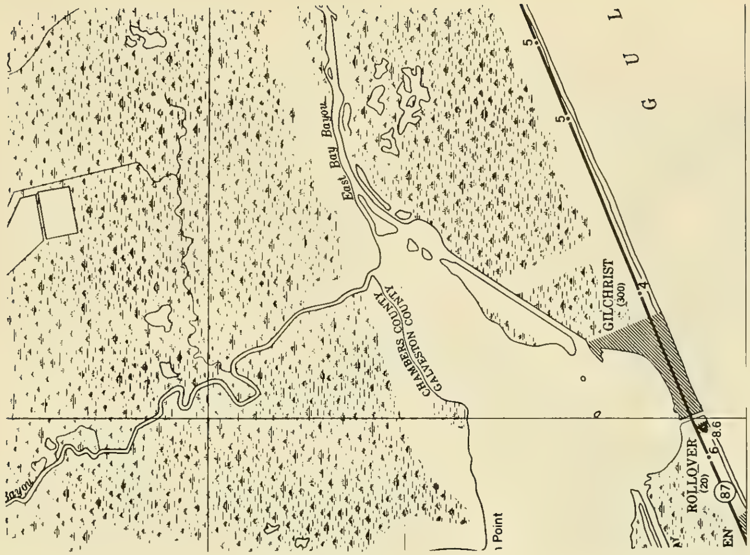

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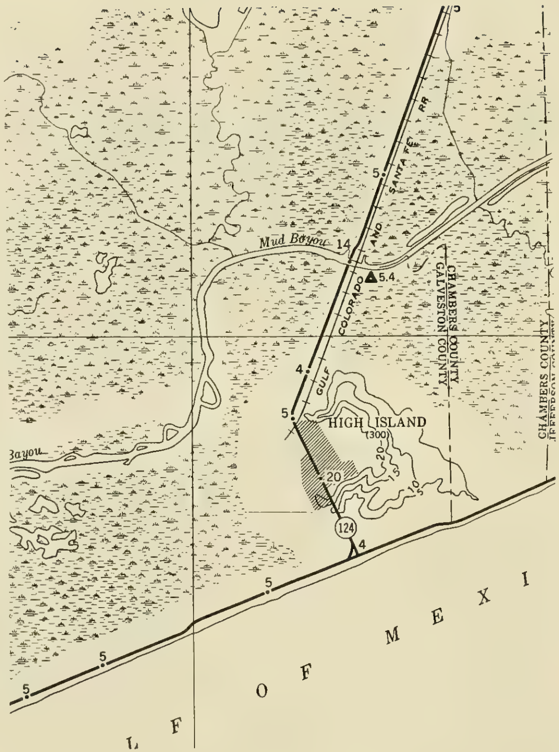

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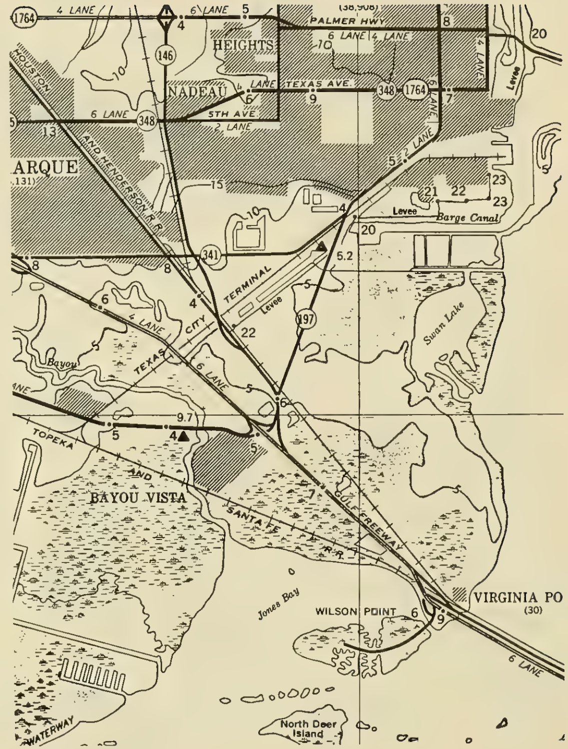

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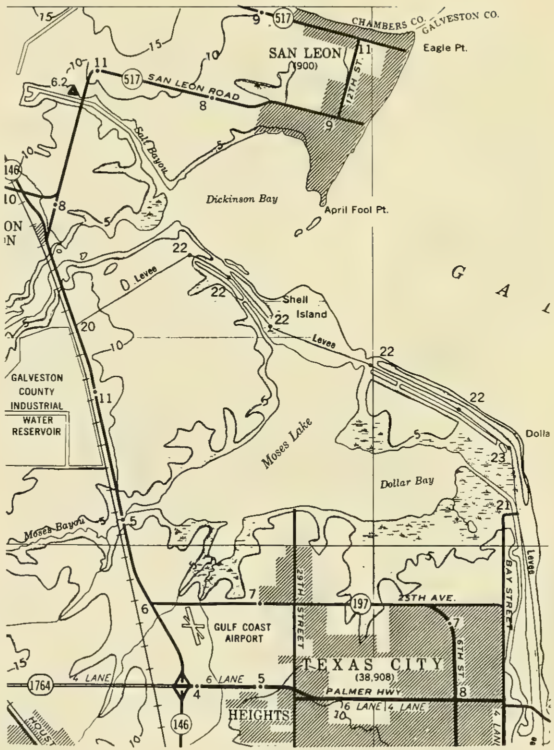

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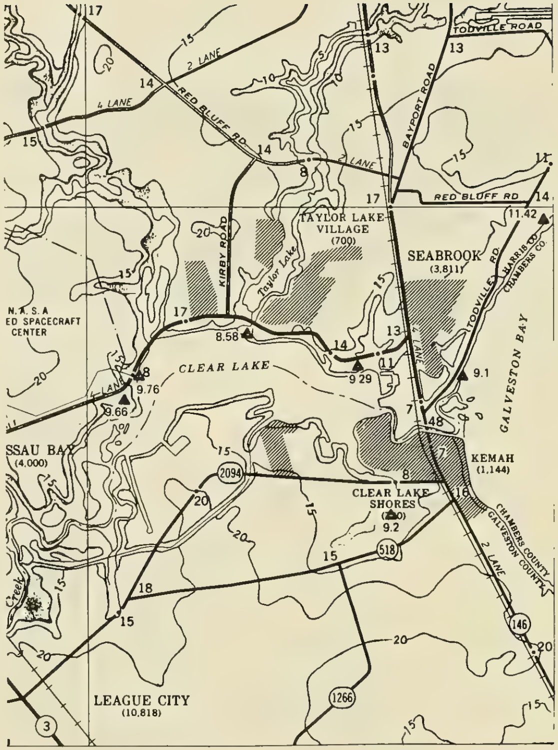
Segment 18



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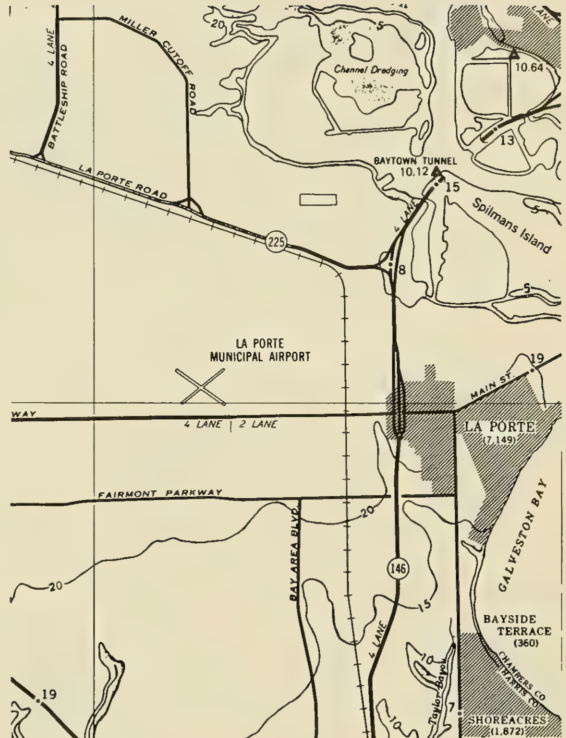

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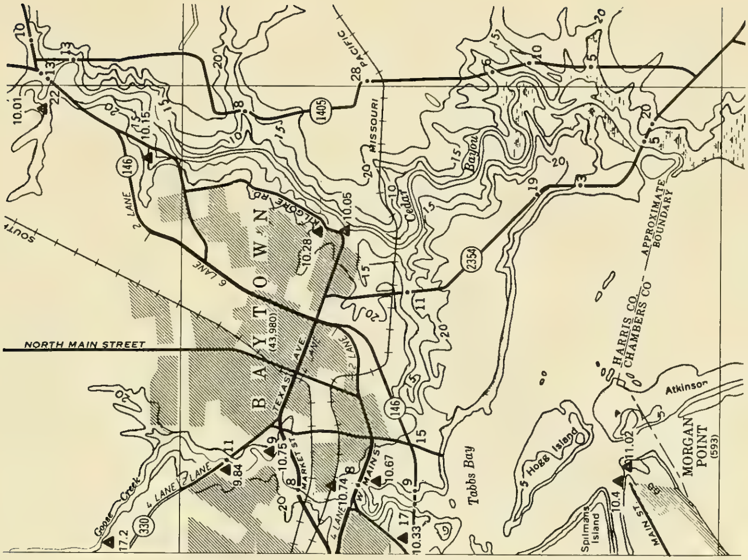

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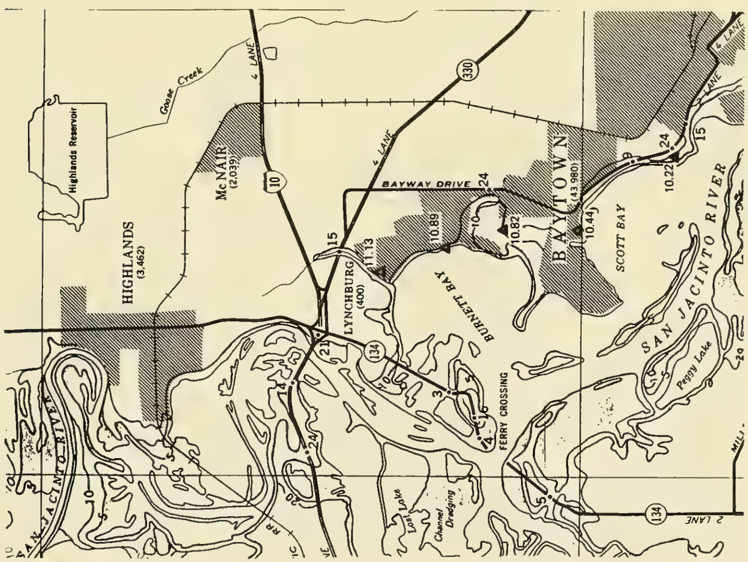

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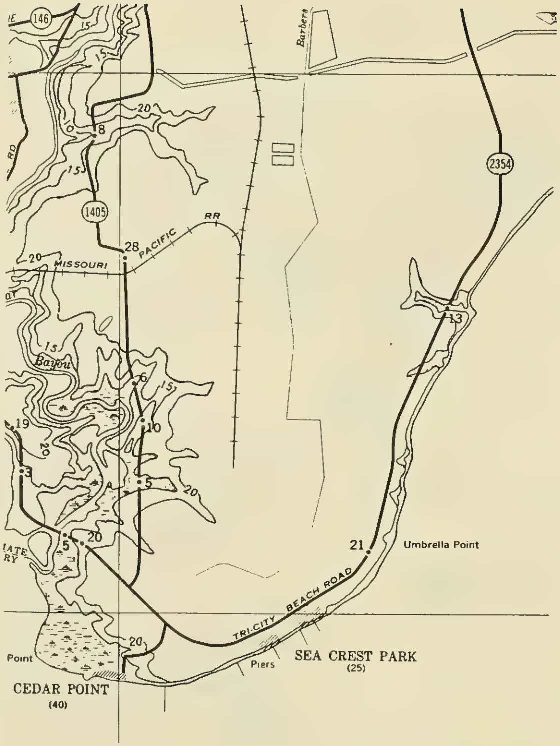

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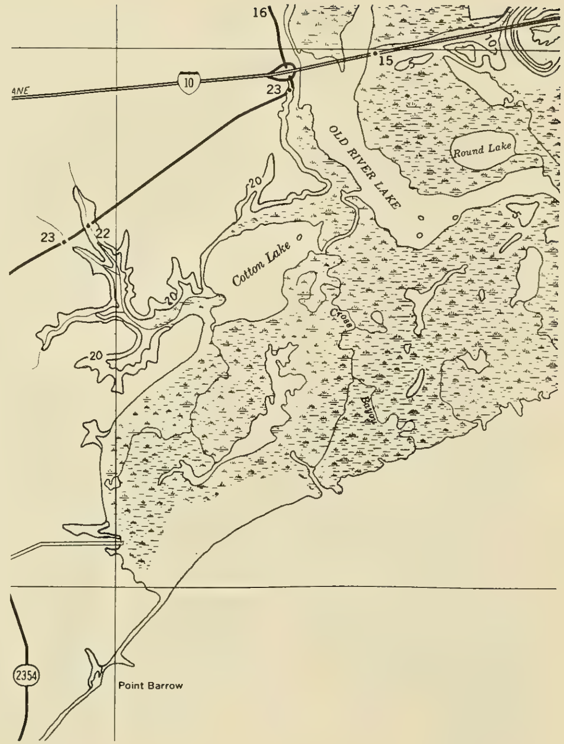

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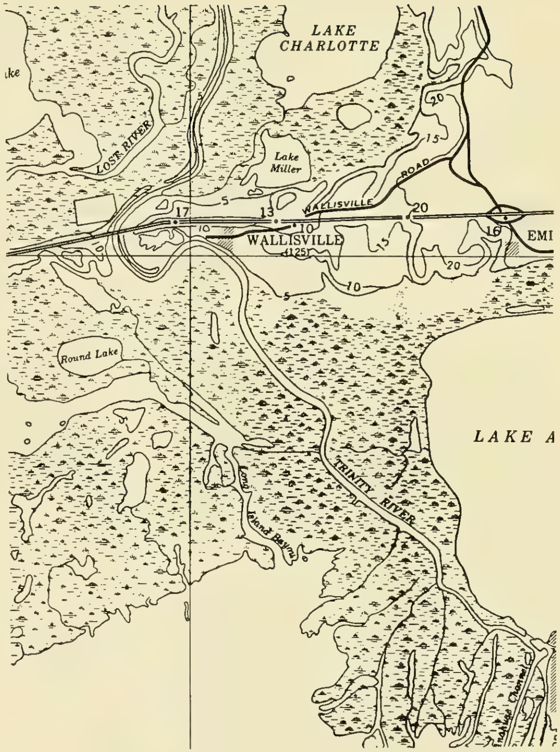

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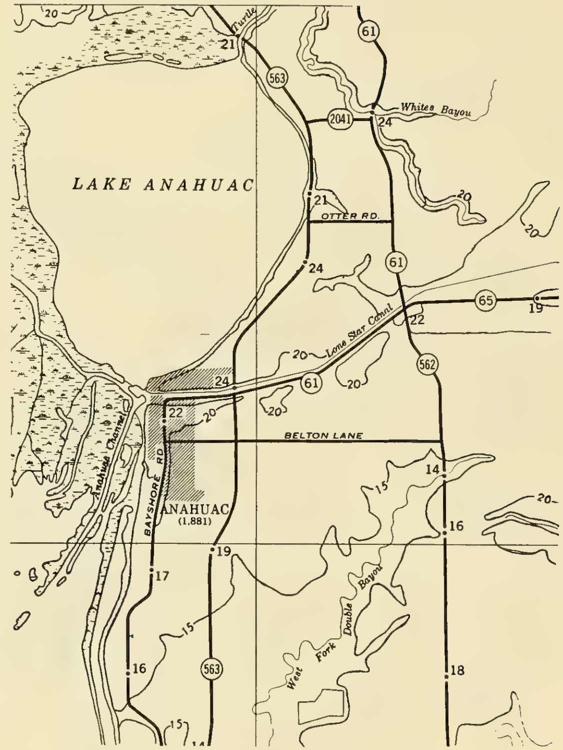

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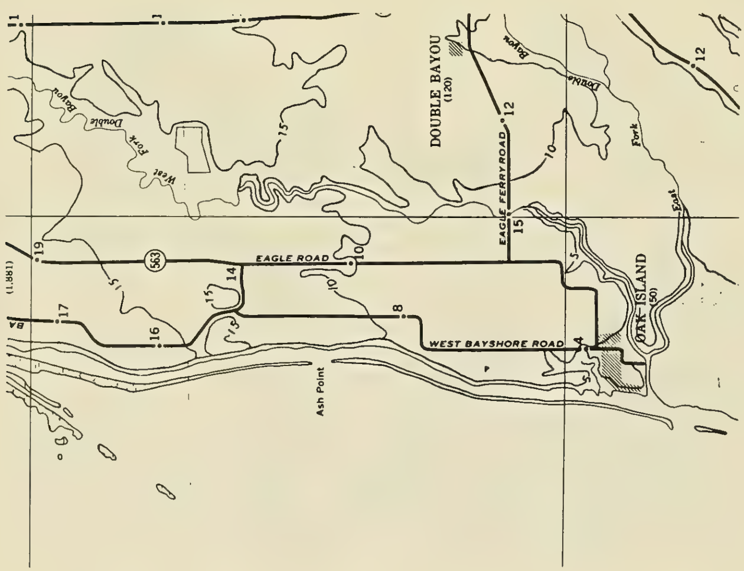

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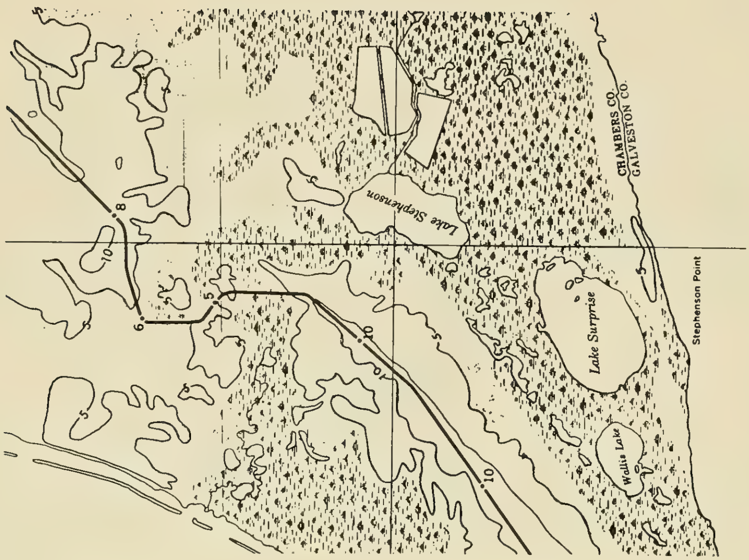

Segment 28

Segment 29

APPENDIX C: INDEX OF AERIAL PHOTOGRAPHY

This Appendix shows the flight lines and photograph numbers for color aerial photography of the Texas Gulf Coast taken on 24 August 1983. Copies of these photographs are available from the National Ocean Service in Rockville, Maryland. Each photograph covers an area of approximately 18 square miles at a scale of 1:30,000. The flight lines cover the coastal area between High Island and the eastern end of Matagorda Bay.

LEGEND

FLIGHT LINE
83CC PHOTO NUMBERS